A SIMULATOR EVALUATION OF PILOT RESPONSE TO AN AIRCRAFT COCKPIT SPIN INDICATOR SYSTEM

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Thesis Advisor: D. M. Layton

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performed for eighteen test subjects during twenty-seven test runs and compiled using eight category classifications. Favorable performance and opinion were obtained. Detailed conclusions and recommendations are presented.

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A high-performance aircraft simulator facility employing a two-axis air combat maneuvering simulation was used to investigate pilot response to an aircraft cockpit spin indicator system. The time required to correctly respond to departed flight, spin, and engine stall indications was measured using F-14 NATOPS procedures. Incorrect and inadequate responses were also recorded. Quantitative and qualitative analysis of sixteen data items was performed for eighteen test subjects during twenty-seven test runs and compiled using eight category classifications. Favorable performance and opinion were obtained. Detailed conclusions and recommendations are presented.

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DEFINITIONS

AC	Alternating Current
ACM	Air Combat Maneuvering
AOA	Angle of Attack
ARI	Aileron Rudder Interconnect
BDHI	Bearing Distance Heading Indicator
bogie	Unidentified Air Contact
CPT	Cockpit Procedure Trainer
DC	Direct Current
EGT	Exhaust Gas Temperature
F/F	Fuel Flow
g	Unit of Gravitational Force
GAC	Grumman Aircraft Corporation
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
rolling scissors	A vertical, or near vertical, maneuver usually involving two opposing aircraft which are attempting to enter, through rolling and pulling, a missile/guns envelope for the other aircraft.

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I. INTRODUCTION

The U. S. Naval Safety Center Weekly Summary of Aircraft Accidents, 7-13 October 1979, reported a spin related F-14 accident. During an Air Combat Maneuvering (ACM) tactics flight against an A-4 adversary aircraft, the F-14 departed controlled flight and was subsequently lost. This highlights a serious problem in the U. S. Navy fighter community: the loss of valuable assets during ACM training due to departure and spin situations.

This problem was examined to determine if any research could be performed at the Naval Postgraduate School toward a solution. Figure 1 is a fault tree analysis of the problem. It was decided to undertake research in the form of preliminary design work and human factors testing of a spin and engine stall cockpit indicator system.

The objectives of this research were:

1. Investigate the problem and ascertain the requirements and factors influencing the design and testing of a spin indicator system.
2. Procure and activate a suitable cockpit for use in the testing. Modify and calibrate the cockpit as required to obtain a full-control simulator capability.
3. Design and construct a spin and engine stall cockpit indicator, as well as a control system

for its operation. The design should be aimed toward incorporation in a current aircraft.

4. Construct a facility for the human factors testing. This facility to include a tracking task simulation of ACM, control capability of the testing, and data acquisition of pilot responses to the indicator system.
5. Conduct testing as realistically as possible in the laboratory, measuring pilot response time to the indicator stimulus, as well as recording the incorrect and inadequate responses as compared to the NATOPS departure/spin procedures for the F-14.
6. Analyze the acquired data to determine the effectiveness of the indicator in improving pilot response. Also, examine the feasibility of incorporating such a system into current and future aircraft. Data should be analyzed to gain information concerning pilot responses in the departure/spin situation, the effects of the different procedures, and the performance of various categories of test subjects. Of particular importance is pilot response during stalled engine procedures.

II. NATURE OF THE PROBLEM

The initial F-14 contract required a standard spin testing program. This was reoriented from spin testing to spin prevention after a pilot-incapacitating flat spin mode was discovered through the NASA-Langley wind tunnel tests and Grumman Aircraft Corporation (GAC) analysis. This flat spin mode was driven by the adverse yaw from the differential tail. Several unsuccessful mechanical fixes were evaluated, including a stick pusher and a lateral stick centerer. The aircraft was at this point still in the non-maneuvering slat configuration. NASA-Langley developed an aileron-rudder interconnect system (ARI) which optimized aircraft performance at high angles of attack and aided in spin prevention through elimination of the spin inducing adverse yaw from the differential tail. The ARI changed the onset Mach number of roll reversals and reduced the severity of the departures. Thrust asymmetry was also evaluated.

The F-14 configuration was then changed to incorporate maneuvering slats. The ARI, also incorporated in this configuration, was not optimized for this configuration and was only superficially tested. The ability of this configuration to sustain an angle of attack greater than 18° caused dutch roll instability (wing rock) to become a problem. The solution to this problem used the ARI to add yaw rate to the rudder schedule at angles of attack above 19° and lateral stick less than one inch deflection. This, however, was a pro-spin input.

The ARI was disabled in F-14 after the loss of aircraft number 186.

Re-evaluation of departure/spin prevention of the maneuvering slats configured F-14 was undertaken by NASA-Langley. The problem of asymmetrical thrust was discovered at low airspeeds and high angles of attack. At this specific combination of flight conditions, a high asymmetric thrust condition can cause a departure/spin situation due to insufficient aerodynamic control forces available to counteract the asymmetric thrust yawing moment. New NATOPS emergency procedures were instituted.

However, F-14 aircraft have continued to be lost due to engine stall/spin accidents. In September 1978, an F-14 Stall/Spin Conference was held at the Naval Air Systems Command, Washington, DC. It addressed the problem of unacceptable aircraft stall/spin related losses. Participants included knowledgeable and experienced engineers, flight crews, and flight test personnel with extensive F-14 experience.

During the conference, the Naval Air Test Center (NATC), Patuxent River, Maryland, presented a review of seven of the F-14 losses which were stall/spin related. Three accidents which occurred in the landing phase were also examined. The analysis indicated an alert pilot following current NATOPS emergency procedures and concentrating only on flying the aircraft could have avoided the accident in six instances, and possibly in nine instances. The following is quoted from the conference report:

"There was general agreement that the F-14 is an honest airplane that can be safely flown in accordance with NATOPS procedures to the extremes of its envelope; but the engine stalls and resultant asymmetric thrust create a hazardous condition during certain flight conditions which require prompt and precise pilot reactions. Preoccupation with anything other than flying the airplane - to recover flight path control - can result in complete loss of control."

"With present cockpit instrumentations it is difficult for the pilot to ascertain yaw (turn) direction during a spin entry and spin."

"There is a problem in recognizing which engine has stalled in the case of hung, low power stalls. It is difficult to immediately tell from the F-14 engine instruments which engine has stalled. The pilot's attention therefore is diverted from flying to determining which engine has stalled and he may allow the aircraft to get away from him. It should be reasonably easy to mechanize a system to unambiguously and quickly identify which engine has stalled."

In the NATC briefing, one of the long range possibilities presented was the incorporation of an "improved spin direction indicator."

This thesis concerns the design, construction, and testing of such an "improved spin direction indicator," as well as an engine stall indicator. The intent of the design was to provide improved instrumentation, yielding quick recognition of yaw

direction, departure or spin condition, and identification of stalled engine. This should then allow the prompt and precise pilot reactions which are required in this demanding situation in order to prevent an aircraft loss.

III. EXPERIMENTAL PROCEDURE

In order to accomplish the previously outlined spin research objectives, it was necessary to measure the responses of test subjects to a spin indicator system in a realistic environment. This dictated that the testing would be accomplished in an aircraft flight simulator that would permit the test subject to simulate, in real-time, maneuvering the aircraft to the extreme edges of its theoretical flight envelope, as is required in Air Combat Maneuvering (ACM) engagements. In addition, it was desired to simulate a high performance, twin engine aircraft, with a cockpit as complete and dynamically functioning as possible. A facility was required along with the flight simulator that was capable of providing: (1) a tracking task approximating ACM, (2) a visual display to the test subject of the tracking task, (3) a spin indicator in the cockpit with an external control mechanism, (4) outputs of longitudinal and lateral stick position, rudder pedal position, and both engine throttle positions, and (5) a measuring/recording system for data acquisition.

A. CONSTRUCTION OF THE FLIGHT SIMULATOR

An F-4 Cockpit Procedures Trainer (CPT), Device 2C30, was obtained from the Naval Training Device Center with the assistance of the Office of the Chief of Naval Operations (OP-596). The CPT was installed in H-024 in Halligan Hall, and power was obtained from the power panel outside H-024. This was one means of emergency shut-down. The External Power Switch for

the CPT was located on the bulkhead behind the CPT control console. This was also a means of emergency shut-down. The CPT was positioned as specified for the standard training mode and the wire connections between the cockpit and the control console were connected. The CPT was activated, repaired as necessary, and its various functions calibrated. Start-up and shut-down was done using the start and stop checklists contained in Appendix A.

The 2C30 CPT was modified in order to convert it into a full control, fixed-base simulator. The control outputs required were lateral control stick, longitudinal control stick, rudder control, and left and right throttle position. The basic approach employed was to install a permanent, reliable, and durable system in order to provide maximum future utilization. Five thousand ohm, center-top potentiometers, compatible with the Aeronautics Department's Pace TR-10 Analog Computer, were selected to monitor control positions in order to have control outputs in positive and negative voltages.

The lateral stick position potentiometer was mounted between two potentiometers already used for the lateral stick position indicating system in the cockpit. This system is located under the frame of the cockpit base in the forward left corner as shown in Figure 2. The longitudinal control position potentiometer was mounted on a locally fabricated bracket, and precisely aligned with the cross-shaft directly below the control stick, as shown in Figure 3. The rudder position potentiometer was mounted on a locally fabricated

bracket which was attached to the system which furnishes rudder position to the cockpit display. This is located in the forward-left corner of the cockpit, and access was through the removable front panel, as shown in Figure 4. The left and right throttle position potentiometers were simply "ganged" on a system of potentiometers already used for operating the engine dynamics of the CPT. This is in the rear of the cockpit and access was through the removed large rear panel as shown in Figure 5, where the black and red potentiometers are "ganged" on the end of the other potentiometers. All potentiometers were modified and adjusted so that maximum positive to maximum negative output was obtained relative to control position due to the requirement to mount some potentiometers in positions where shaft movement was minimal. All potentiometers were wired for a positive input (red wire), a negative input (black wire), and an output (white wire). The specifics of the potentiometers and the points wired are provided in Appendix B. The wiring from all potentiometers was routed, using permanent attachments to the cockpit interior, to the rear of the cockpit and attached to new Terminal Boards 19 and 20, which were installed for this purpose. Appendix C contains the connections listing of these terminal boards. A bracket was attached below the terminal boards, and an Amphenol 28-12 plug and cable was used to connect the cockpit system with the console control system. Appendix C also contains these plug connections. Figure 6 shows Terminal Boards 19 and 20 as well as the plug connection in the rear bay of the

cockpit. The cable was run through the interior of the cockpit and then out the bottom of the cockpit and underneath to the control console and up into the center section of the control console. The connection/control system for the cockpit controls was mounted in the center section of the controller's console, beneath the Master Control Panel. On the inside of the panel were mounted a bracket and plug to attach the cable from the cockpit, a terminal board for positive voltages, a terminal board for negative voltages, and a 12 V-DC ON-OFF toggle switch, and five (5) color coded Banana Jacks, each with a parallel BNC connector. The inside of the control panel is shown in Figure 7. Installed on the interior floor are two (2) Power Mate Corporation, Model BP-34c, power supplies capable of supplying positive and negative voltages up to 36 volts (DC). The power supplies were set at $\pm$ 12 volts (DC). The power supplies receive 110 volt AC power from the Procedures Slide Projector system. It is therefore necessary to push (turn on) the SLIDE SYS-12V POWER to CONTROLS button on the Master Control Panel to get power to the power supplies. This control has been re-labeled to include the power supply function. The ON-OFF switches on the power supplies themselves were left on since this compartment is not easily opened.

The power supplies, shown in Figure 8, are connected to the 12 V-DC ON-OFF switch by a quick disconnect plug. With the ON-OFF switch in the ON position, the power supplies provide the positive and negative voltages to the two terminal boards, which then supply power to the potentiometers through the

connecting cable. Control, or potentiometer, outputs are returned through the system to the output terminals. Figure 9 shows the exterior of the control panel with the 12 V-DC ON-OFF switch and ten (10) output terminals. The control outputs, in the form of direct current voltages from - 12 volts to + 12 volts, were available for (1) input to the analog computer for the tracking task, and (2) recording control positions during the test.

A cloth enclosure was rigged around the cockpit to deprive the pilot (test subject) of external references during testing.

Upon completion of the modification, the longitudinal and lateral stick, the rudder, and the two throttle output potentiometers were adjusted in position for calibration of the outputs. The stick and rudder outputs were taken as a function of force (pounds-force, lbf) and displacement, or deflection, (inches) from neutral. Figure 10 shows output voltage vs. longitudinal stick force, while Figure 11 gives voltage vs. longitudinal stick displacement. Likewise, Figures 12 and 13 show output voltages vs. lateral stick force and displacement, and Figures 14 and 15 show voltages vs. rudder pedal force and displacement. Of note are the dead bands in the longitudinal and lateral stick control. Also noteworthy is the similarity to actual aircraft force vs. displacement curves. This calibration data was obtained with all controls trimmed to the neutral position as indicated by Neutral Lights on the controller's console.

B. CONSTRUCTION OF THE SPIN INDICATOR

It was necessary to design and construct a spin indicator system consisting of a controlling mechanism and an indicator that would display departure, spin, and engine stall information. Previous work done on spin indicator systems at the Naval Air Test Center, Patuxent River, Maryland and at the U. S. Air Force Test Pilot School, Edwards Air Force Base, California was investigated.

Although the testing could have been conducted with but visual light cues, a system was designed that could interface with an actual aircraft, specifically the F-14A. This design, then, could be the first developmental step toward a piece of actual aircraft hardware. Assistance was obtained from the NASA personnel of the Navy/NASA High Angle of Attack ARI Test Program. Figure 16 contains a block diagram of the conceptual design which was formulated. In order for the indicator system to be enabled, indicated airspeed must be below 90 knots and weight of the aircraft must be off the wheels. The ARI system would be used to provide angle of attack and yaw rate data to the system, and the turn needle sensing system would provide the signal necessary to determine yaw direction. Angle of attack of 28-30 units (for an upright condition) or 0-2 units (for an inverted condition) would enable the system. A yaw rate less that 35° per second would produce a flashing signal, (the departure signal), and a yaw rate greater than 35° per second would produce a steadily illuminated signal, (the spin signal). These yaw rates would only produce an aural warning

tone and an appropriate signal, in the direction indicated by the turn needle sensing system, if all other conditions were satisfied. The signals designed for display to the test subjects were colored arrows, red for the left directional arrow and green for the right directional arrow. There is a new engine stall warning system presently installed in F-14A aircraft number 1X being utilized in the Navy/NASA High Angle of Attack Test Program. This would be used to display a stalled engine indication to the indicator system. The engine stall signals designed for display to the test subjects were two red lights, one mounted below each directional arrow. The one on the right side of the indicator was for a right engine stall indication and the one on the left side of the indicator was for a left engine stall indication.

The spin indicating circuit was modified slightly, as shown in Figure 17, so that a breadboard model and eventually test hardware could be made. Figure 18 shows the breadboard model of the spin indicating system using a Circuit Design Test System and Digi Designer. This successful design was then transferred into hardware for the test program.

The designed circuit was placed in the control box which is shown in Figure 19. The source of power is 115 volt AC. This is converted into 5 volt DC power for use in the logic circuits. ON-OFF switches function as the inputs enabling the various circuits of the system (i.e., Function Switch 6 ON indicates weight is off the wheels, Function 5 ON indicates airspeed is less than 90 knots). Status lights on the control box indicate which indicating circuits have been enabled, as

well as what outputs are being transmitted. Upon activation of the various indicating circuits, the signals are sent to the spin indicator. An internally mounted timer times the test evolution. In addition, one ouput to the analog computer causes the displayed signal on the X-Y Display to disappear.

Three outputs to the recording system allow for the exact time to be recorded at which the various signals are displayed to the test subject. Pull-up transistors were used to boost the voltages from the control box to the indicator for brighter illumination of the signals.

The indicator itself, mounted in the cockpit, is shown in Figure 20. A small metal box was fabricated to fit on the curved glare shield, with its interior divided into compartments in order to preclude light from one signal illuminating another lens. A left and a right arrow were cut in the front of the box, with a red and green lens, respectively, placed behind them. Two light emitting diodes (LEDs) were placed behind each arrow for illumination. A red LED was mounted below each arrow as the engine stall indicators. The wiring for the indicator was routed through the interior of the cockpit out to the control box.

C. CONSTRUCTION OF THE FACILITY

The facility was constructed around the flight simulator. Figure 21 is an overall view of the facility. Shown is the flight simulator with its enclosed cockpit (Figure 22) and the

controller's console that was used to control both the cockpit and simulator functions (Figure 23). Also shown are the various equipments used in the testing. A list of the equipment used to construct the facility is contained in Appendix D. The components requiring control during the test sequence were placed at the control position, and other components were placed as required for the testing procedure. The control position is shown in Figure 24. At the control position were placed the tape deck, analog computer, the spin indicator control box, and the signal control box. The spin indicator control box was placed next to the tape deck and analog computer, as these equipments had to be monitored and controlled during the short time interval of each individual test.

One track of the four track tape deck was dedicated to an aural briefing and aural prompts during the test procedure. Two other tracks were used in the tracking task, and will be described later. A transcript of the aural briefing and prompts is contained in Appendix E. Headphones were installed in the cockpit to provide the test subject with the output of the aural track of the tape deck. The wiring for the headphones was routed through the interior of the cockpit and out to the control position where it was connected to the tape deck.

A signal control box, also used at the control position, is shown in Figure 25. It was manufactured locally to accomplish several purposes. Figure 26 shows the relationship of the signal control box to the facility. The specific functions

of the signal control box will be discussed as the tracking task is described.

The tracking task used in the testing procedure simulated ACM to the best extent possible in this laboratory environment. The outputs of the flight simulator were all routed to the signal control box using coaxial cables. The longitudinal and lateral stick outputs were the inputs to the analog computer circuits, shown in Figure 27, that were used to amplify the signals and simulate aircraft response. The longitudinal circuit approximates the Short Period motion of a high performance, fighter type aircraft at 0.9 Mach. The output used was angle of attack, α , effected by the dynamic short period mode. This was required since any pitch angle, θ , resulting from an elevator input, δ_e , would remain in the circuit until removed due to the lack of airspeed and/or altitude change in this circuit. The angle of attack, however, varied as a function of the analog computation of δ_e , very closely approximating the dynamics of pitch rate at high α found in ACM. The lateral circuit is an approximation of roll response, ϕ , from lateral inputs to a stable aircraft. In this circuit, a step input will return to the null position after the input is removed. These two outputs, α and ϕ , were then used as inputs to the two summing circuits, shown in Figure 28.

The two tracks of the tape deck used in the tracking task contained the previously recorded, two-axis signal approximating the target aircraft, or bogie, in the tracking tasks. An

analog reproduction of these signals is shown in Figure 29. The tape used in the test procedure had three trial tracking tasks and a test sequence, all separated by rest periods. The sequence of events on the test procedure tape recording are contained in Table I, as defined by counter reading and time intervals. The trial tracking tasks were designed to familiarize the test subjects with the tracking task, the flight simulation effects, and the test environment, with the trials arranged in increasing order of difficulty. The two signals from the tape deck were transferred to the signal control box using coaxial cables. In the signal control box, a 1500 MFD 50 VDC capacitor was added to each of the signal circuits from the tape deck in order to eliminate extraneous noise which apparently was originating in the tape deck reproduction section. This provided a sharp, clear signal for display to the test subject for tracking. These two reproduced signals were used as the other inputs to the summing circuits of Figure 28.

The summing circuits compared the taped signals and the outputs from the flight simulator, and the differences were displayed to the test subject. The test subject was then able to vary the controls in order to "zero" the displayed signal. The x and y axis outputs from the summing circuits were fed to the x-y display for the tracking presentation and to the oscilloscope for test monitoring.

In order to display the tracking task to the test subjects, a Hewlett-Packard X-Y Display was used as shown in Figure 30.

The X-Y Display was mounted so that the test subject seated in the cockpit had a frontal view of the display unit by looking up at a 40 degree angle and 70 degrees to the right of the aircraft nose. This approximates very closely the typical, if not the predominant, head position of a pilot engaged in ACM (see Figure 31). The objective of the test subject's tracking task was to keep the signal centered on the X-Y Display unit. Cross-hairs were placed on the face of the display unit to aid the test subject in centering the signal (Figure 32). Centering the signal was accomplished by maneuvering toward the tracking task signal, since it represented the bogie. For example, if the bogie was to the left and above the center of the screen, the proper maneuver inputs would be left lateral stick and aft longitudinal stick displacements sufficient to center the signal on the screen.

Predominantly, the test subject was required to pull aft longitudinal stick of varying displacements while using varying displacements of left and right lateral stick displacement. This task approximated pulling varying angles of attack at various angles of bank. This would have been similar to the test subject having been engaged in ACM, starting as a rolling scissors (overhead maneuvers requiring various roll maneuvers) and degenerating to a point of less energy. This latter part of the test sequence required large aft stick displacements and large lateral stick displacements, those inputs being ones which could very likely result in a departure/spin situation.

The progress of the test subject in the tracking task could be monitored by viewing the oscilloscope which was mounted on the top, center portion of the controller's console, facing the control position as shown in Figures 21 and 33. The oscilloscope was set up on a scale three times that of the X-Y Display. Therefore, if the test subject inadvertently maneuvered the aircraft such that he lost sight of the tracking task signal, the test controller could locate the signal by reference to the oscilloscope. In addition, the controller could monitor the test progress by using several additional circuits in the analog computer.

The signal control box transferred via coaxial cable all of the flight simulator outputs to an eight-track analog strip chart recording system, shown in Figure 34. It was located next to the control position and recorded data during the testing. The channelization of the strip chart recorder is shown in Table II. The inputs to Channels 1-3 came directly from the spin indicator control box and the inputs to Channels 4-8 came from the cockpit controls via the signal control box.

D. TESTING PROCEDURES

Before each test series, the facility equipment had to be turned on, adjusted, and calibrated. This procedure took approximately one to two hours. The pre-test procedures, as well as the actual testing procedures, are listed in Appendix F.

A briefing was given orally to each individual participating in the program. An outline of the briefing is contained

in Appendix G. Each individual completed the Spin Indicator Response Project Interview Questionnaire, a copy of which is shown in Appendix H. The questionnaire was assigned a Test Run Number and dated.

Upon completion of the briefing, the test subject would enter the cockpit and don the headphones. Lighting in the laboratory was dimmed to a predetermined level for optimum indicator signal illumination. The laboratory door was secured to prevent intrusions during the testing. The eight-track recording system was started at 5mm per second speed with the "divide by 100" button depressed. The recording graph paper was labeled with the assigned Test Run Number. The tape deck was started so that the test subject could hear the taped briefing (Appendix E), during which all of the various departure, spin, and engine stall indicators were illuminated as the taped briefing described them. After this display of the signals, the spin indicator control box was configured for the left departure, left engine stall, left spin situation and the internal timer set to zero while the test subject received the remainder of the briefing. When the trial and test tracking tasks started, the analog computer was placed in the operate mode. During the rest periods in betwwen tracking tasks, the computer was placed in the reset mode, insuring the next tracking evolution would start at the center of the X-Y Display. Before the test subjects entered the actual test tracking, they were advised by the tape to select maximum afterburner and stand-by for the test tracking using simulated ACM. This test

tracking lasted approximately three minutes. At approximately the two and a half minute point, the recording system was put at the test recording speed (5 mm/sec). The test subject's tracking was monitored and toward the end of the sequence, at a time when the test subject was using maximum aft stick and maximum lateral stick displacements, the left departure signal was activated on the control box. This caused, simultaneously, the left red arrow to flash, the tracking signal to disappear from the X-Y Display, Channel 1 of the recording system to record the event, and the internal timer to start. At approximately three seconds after the departure signal, the left engine stall signal would be activated at the control box. This caused the left engine stall indicator light to illuminate and Channel 2 of the recording system to record the event. Approximately nine seconds after the initial departure signal, the left spin signal would be activated at the control box. This caused the flashing left red arrow to be steadily illuminated and the event to be recorded on Channel 3. The test was allowed to proceed for ten to twenty seconds past this point and then terminated. Equipment was stopped and readied for the next test, and the end point was labeled on the recording graph paper.

All testing was done using the procedures as described. No testing was done using a right departure/spin situation, nor with the engine stall preceding the departure situation. Due to the limited number of test subjects available, all test-

ing was done in the same direction and sequence for data comparison purposes.

E. TEST SUBJECTS

The test subjects participating in this evaluation of the spin indicator system were military officers attached to the Naval Postgraduate School, either in the Aeronautics Programs or the Aviation Safety School. A total of twenty-seven (27) tests were performed using eighteen (18) subjects. Nine (9) subjects performed the test twice. The test subjects were categorized into the classifications as shown in Table III. All test subjects were designated aviators with the exception of Category O, which contained interested naval flight officers desiring to participate in this experiment. Among the test subjects was one female designated Naval Aviator. The test subjects ranged from the rank of Lieutenant to Commander, U.S.N., and Captain to Major, U.S.M.C. and U.S.A. Experience levels ranged from 900 to over 3000 total pilot hours. Seventeen (17) of the test runs were performed using Aeronautics Program students, and ten (10) runs utilized Aviation Safety School students. In general, the Aeronautics Program test subjects had completed either their first or second operational tour of duty immediately prior to entering the Naval Postgraduate School, and at least six months had passed since their last operational flying. The Aviation Safety School students were all attached to operational squadrons. Of particular note is the previous spin training the test subjects had received; 83.3 percent of the test subjects had previously received some spin

training. All of these had received spin training in actual aircraft. In addition, 22.2 percent had received spin training in a flight simulator.

IV. PRESENTATION OF DATA

The eight-track analog strip chart recording system acquired all the data for each test run. Figure 35 is a sample of data acquired on a typical test run. Shown are the applicable time intervals as well as the channelization which was previously described. Each test run was analyzed and sixteen (16) data points were obtained from each test run. These specific items are identified on the Data Analysis Form, a sample of which is contained in Appendix I. The time a test subject required to attain each of the required control inputs was measured to the tenth (0.1) of a second (items 1.b., 1.c., 1.d., 1.e., 2.b., 2.c., and 3.b.). Then, the largest time response in the departure, spin, and engine stall phases was used to determine the overall time required to attain the required control inputs for each phase (items 1.a., 2.a., and 3.a.). The data acquisition system allowed the correctness and adequacy, as well as the time, of the responses to be observed. If a control input was not fully applied, or not fully maintained, during the test run, it was counted and recorded as an inadequate response (items 1.g., 2.e., and 3.d.). If an input was not applied at all, or applied in the wrong direction, it was counted and recorded as an incorrect response (items 1.f., 2.d., and 3.c.). If a required control input was never achieved, no time response was taken, but counting this as an incorrect response served as the penalty for the error. Examples of inadequate responses recorded were:

- "lateral stick input returned to netral for 0.5 sec. during spin phase"
- "rudder not at full deflection during engine stall phase"
- "forward stick input not maintained during departure phase"

Examples of incorrect responses recorded were:

- "aft longitudinal stick applied before correct input during departure phase"
- "applied lateral input for 0.5 sec. during departure phase"
- "lateral stick oscillated between neutral and full left positions during departure phase"
- "only retarded one engine to IDLE during engine stall phase"
- "applied lateral input in wrong direction during spin phase"
- "never put stalled engine throttle to OFF during stalled engine phase"

The data was compiled into the test subject categories as previously described. For each category, the sixteen (16) data items were compiled to obtain a mean and standard deviation. A new mean was computed for the sixteen items in each category, discarding any data which was outside the bounds of the mean plus or minus 1.96 times the standard deviation. This meant that data considered had to be in the 95 percentile confidence bounds of the normal distribution.

This allowed for the fact that some test subjects stated they had difficulty in moving the throttles and some were totally unfamiliar with the environment presented. Only twenty-six (26) out of four hundred five (405) data points, or 6.4%, were discarded as being outside of these bounds.

Figures 36 through 50 display the results of this data compilation in bar graph format. The mean times required for the various responses are shown in Figures 36 through 44. Each of these figures displays data for one individual response item as a display of the time each category required. Figures 45 through 50 display, for the incorrect and inadequate response items, the mean value of the number of responses for each category. In all cases the mean values are less than one (1.0), indicating that all categories had less than one incorrect and one inadequate response per test subject in each of the three test phases (departure, engine stall, and spin).

The validity of test data in human factors testing is subject to question unless care is taken in the design of the experiment, selection of the test subjects or their classification, and analysis of the data. This experiment was designed to acquire data on observable responses to very specific and standardized stimuli. Since the type of test subjects available was limited, the classification into the various categories was important. The data analysis had to be standard in nature, as well as being based upon definite, observable actions.

Appendix J contains the comments, both favorable and unfavorable, concerning the spin indicator used in the testing. Comments quoted are predominantly those from the test subjects in the Tactical Aircraft Category, which included graduates from the U. S. Navy Test Pilot School and a spin instructor pilot from VF-126. A qualitative analysis of these comments is that they are largely favorable in nature. In addition to their comments, the eighteen (18) test subjects were asked to answer the following two questions:

- Was the test indicator better than current instrumentation?
- Do you recommend this, or something similar for fleet aircraft?

Twelve (12) test subjects answered "YES" to both questions, while five (5) did not answer the questions. Only one individual answered "NO", specifying his answers were concerning the departure/spin part of the indicator.

V. CONCLUSIONS AND RECOMMENDATIONS

The testing of the various subjects in the departure/spin environment revealed what a truly demanding situation this presents to any pilot. It is not difficult to understand that even experienced fighter pilots have failed to react appropriately in these circumstances. In analyzing the results of this project, it must be recognized that a limitation exists. Cockpit presentations using conventional instrumentation were not evaluated as a data base. Testing using a movable attitude indicator, movable needle and ball, movable angle of attack and airspeed indicators, and conventional engine indicators was not performed. This was due to limitations in time and material support.

However, keeping in mind that limitation, analysis of the data presented reveals the following information concerning pilot responses, the spin and engine stall indicator system, and the departure/spin environment.

o The more steps or specific procedures there are in an emergency situation, the longer it will take a pilot to accomplish them. The departure and engine stall procedures demonstrate this obvious fact when compared to the simple, one-step spin procedure.

o With training and repetition, a pilot's reaction time improves. Category R performed significantly better in almost all areas of testing. Of note is the fact that Category R was only taking the test for the second time. A sizable

improvement could be expected with more training. However, in a real departure/spin situation, the time response would also be influenced negatively by such factors as surprise, anxiety, and violent aircraft motion.

o The critical factor in an F-14 engine stall/spin situation is the elimination of high asymmetric thrust conditions. Indications revealed here are that more than three seconds are going to be required to retard both throttles to Military Power in a departure. Also, more than three seconds will be required to retard both throttles to Idle Power when a stalled engine situation arises. These times are those demonstrated by Category R, which should reflect an optimum. Rather high reaction times are revealed for the other categories. It is obvious how the spin problem can develop with reaction times of this magnitude.

o The proficient tactical pilots, Category TP, did not achieve results significantly better than the other categories in some test items. This may be due to the fact that few of this category were F-14 qualified, and were therefore knowledgeable in other departure/spin procedures. Category TP performed exceptionally well in their initial reaction to the departure (rapid attainment of full forward stick and neutral lateral stick).

o Of note is the exceptional performance of the non-pilots, Category O. Since this category was unhindered by previous training, both in procedures and with conventional

instruments, it is concluded that pilots trained on a system such as this one can achieve remarkable reaction performance. The negative factor in this context is that totally automatic responses are being encouraged, "monkey-style", as opposed to intelligent analysis of the situation.

o There was exhibited a high level of incorrect and inadequate responses in the departure phase. The criticality of correct and adequate responses here is obvious, yet the statistics indicate that at least one out of three pilots made an incorrect response, and at least one out of three made an inadequate response.

o The relatively low level of incorrect and inadequate responses in the stalled engine and spin phases is concluded to be a function of the simplicity of these procedures. Also, it appears to take more time to accomplish engine related procedures (retard throttles, secure an engine), but with fewer mistakes being made, than to accomplish flight control procedures.

Concerning the spin and engine stall indicator system, the following conclusions and recommendations are made:

o An engine stall indicator system similar to this system would be advantageous in improving pilot reaction time in stalled engine situations. Specifically, the identification of which engine has stalled should provide faster pilot response times. Although this fact cannot be fully supported due to the limitation previously described, comments of the test subjects (see Appendix J) combined with the data pre-

sented indicate this to be so. A system similar to that presently installed in Aircraft 1X, being used in the NASA High Angle of Attack Testing, would seem to be the best candidate due to its warning capability. The mechanization of warning lights should not present a significant developmental problem. Some suggestions for their location are contained in Appendix J.

o A spin indicator system as described, or some derivative thereof, would be more difficult to interface with aircraft systems. Additional development would be required. Specific improvement in response times cannot be definitely ascertained due to the limitation previously mentioned. However, some benefits from such a system are obvious, and are supported by the test subjects responses and comments (see Appendix J). This would support the contention that such a system would improve pilot response in a departure/spin environment.

Some specific recommendations resulting from this work are:

o Install engine stall indicators similar to those described in F-14 aircraft.

o Conduct additional testing of suitable test subjects in a conventional environment, using a movable attitude indicator, angle of attack gage, airspeed gage, needle, and ball. Use this data for comparison with that obtained herein.

o Commence developmental work on a spin indicator system, or at least an improved yaw (turn) direction system for incorporation into future fighter-type aircraft and possible retrofit into existing fighter inventory. Mechanization of such a system could possibly interface with existing F-14 software to present flashing and solid arrows to the pilot on the cathode ray tube Vertical Display Indicator.

o Emergency procedures need to be kept to an absolute minimum to reduce the number of incorrect and/or inadequate responses.

o Install a flight simulator and testing facility similar to the one described herein at NAS Oceana and NAS Miramar for utilization by fighter crews in conjunction with spin flight training programs, such as the one conducted by VF-126. Since all responses can be recorded for analysis, pilots could train repeatedly until stick movements and throttle movements executed were timely and without error.

APPENDIX A

Abbreviated START Procedure

(1) External Power Switch — ON

This supplies power to the CPT circuit breakers.

(2) Main Power Circuit Breaker (CB1) — ON

This is located inside far right-hand doors. It supplies power to all power supplies.

(3) START Button on control console — PUSH

This starts all power supplies, applies power to CPT systems including cockpit.

(4) SLIDE SYS-12V POWER Button — PUSH

This turns on the slide system and supplies power to the power supplies installed to operate the control system.

*(5) FREEZE Button

Push this button when ready to actually operate engine controls or gages or operate other cockpit systems. Need not be pushed to operate the control monitoring system.

Abbreviated STOP Procedures

(1) Always ensure all servos are at zero position. All engine gages should be at zero, and all cockpit gages should be at zero.

(2)	FREEZE Button	PUSH
(3)	Slide Sys-12V Power Button	PUSH
*(4)	STOP Button under guard on console	PUSH
*(5)	Main Power Circuit Breaker (CB 1)	OFF
(6)	External Power Switch	OFF

*Wait 3-5 minutes after previous step before completing this step.

APPENDIX B

POTENTIOMETERS INSTALLED

For Longitudinal Stick Position

Serial #S53051 452

Color - Black

Output - Terminal 2

Positive Input - Terminal 5

Negative Input - Terminal 7

For Lateral Stick Position

Serial #S53058

Color - Blue

Output - Terminal 2

Positive Input - Terminal 6

Negative Input - Terminal 5

For Rudder Position

Serial #S53059

Color - Blue

Output - Terminal 2

Positive Input - Terminal 5

Negative Input - Terminal 6

For Right Throttle Position

Serial #R20-502x

Color - Red

Output - Terminal 2

Positive Input - Terminal 3

Negative Input - Terminal 1

For Left Throttle Position

Serial #R18-502x

Color - Black

Output - Terminal 2

Positive Input - Terminal 3

Negative Input - Terminal 1

Wiring Code: White - Output

Red - Positive input

Black - Negative input

APPENDIX C

CONNECTIONS LISTING OF TERMINAL BOARDS 19 AND 20

TB 19				TB 20			
1.	Left Throttle	(+IN)	M	1.	Lateral Stick	(+IN)	N
2.	Left Throttle	(OUT)	L	2.	Lateral Stick	(OUT)	P
3.	Left Throttle	(-IN)	K	3.	Lateral Stick	(-IN)	R
4.	Right Throttle	(+IN)	J	4.	Longitudinal Stick	(+IN)	S
5.	Right Throttle	(OUT)	H	5.	Longitudinal Stick	(OUT)	T
6.	Right Throttle	(-IN)	G	6.	Longitudinal Stick	(-IN)	U
7.	-			7.	Rudder	(+IN)	V
8.	-			8	Rudder	(OUT)	W
9.	-			9.	Rudder	(-IN)	X
10.	-			10.	Ground		b

Code: +IN - Positive input

OUT - Output

-IN - Negative input

Letters indicate connection in the connecting Amphenol 28-12 plug.

APPENDIX D

LIST OF EQUIPMENT

1. Flight Simulator

   F4B Aircraft Cockpit Procedures Trainer,

   Device 2C30 (modified)

   Burteck, Inc.

2. Analog Computer

   PACE TR-10

   Electronics Associates, Inc.

3. Tape Deck

   ALPHA 434 (one-quarter inch, reel-to-reel, 4 track)

   Midwestern Instruments

4. X-Y Display

   Model 1300A

   Hewlett-Packard Co.

5. Oscilloscope

   Model 401A

   Allen B. DuMont Labs, Inc.

6. Spin Indicator

7. Spin Indicator Control Box

8. Analog Recorder (8-track)

   Eight-Channel

   Gould Brush

9. Circuit Design Test System

   Elite 3

   EL Instruments, Inc.

10. Digi Designer

DD-1

EL Instruments, Inc.

11. PMC Power Supplies (2)

Model BP-34C

Power Mate Corporation

APPENDIX E

TRANSCRIPT OF TAPED BRIEFINGS AND INSTRUCTIONS

(General Briefing)

The purpose of this project is to evaluate pilot response to a spin indicator system. The objective is to measure the time a pilot requires to respond to departure indications, spin indications, and stalled engine indications. The number of incorrect and inadequate responses will also be measured. The indicator itself is mounted before you on the top of the glare shield, in the center. A green flashing arrow means that the aircraft has departed controlled flight with right yaw rate. A solid green arrow illuminated indicates that the yaw rate has increased to the point where the aircraft is entering a spin to the right. A red flashing arrow indicates the aircraft has departed controlled flight with yaw rate to the left. A solid red arrow illuminated means that the left yaw rate has reached the point where a left spin situation exists. A red light illuminated below the green arrow indicates the right engine has stalled. A red light illuminated below the red arrow indicates the left engine has stalled.

In the cockpit, the following gages are inoperative: the left EGT gage, and the left fuel flow gage. The following instruments are stationary: the attitude indicator, the needle/ball indicators, and the BDHI. The altimeter, airspeed gage, and angle of attack gage will not vary during the exercise. All responses should be made by reference to the spin indicator only. The throttles will be at IDLE during the trial tracking

tasks, and at MAXIMUM AFTERBURNER during the test sequence.

(Tracking Task Briefing)

The plotter above and to the right of you will display a pip which will represent a bogie. This tracking task was designed to simulate ACM to the best extent possible in the laboratory. The objective of the tracking task is to keep the bogie centered on the screen. This is done by pulling toward the bogie. If the bogie is above the center position, pull aft longitudinal stick. If the bogie is to the left of center, apply left lateral stick. The sequence of events in the experiment will be:

(1) a zero signal with the bogie centered on the screen will appear,

(2) a 45 second Vertical Trial Tracking Task,

(3) a 15 second rest period,

(4) a 45 second Horizontal Trial Tracking Task,

(5) a 15 second rest period,

(6) a 75 second Two-Axis Trial Tracking Task,

(7) a 45 second rest period, and

(8) approximately 3-1/2 minutes of simulated ACM in maximum afterburner.

During this ACM, the aircraft will depart controlled flight. This will be apparent by the bogie disappearing off the screen. At this time your responses to the spin indicator are being recorded. You are to use standard F-14 NATOPS procedures for an upright, flat departure/spin situation:

Departure (1) stick - forward/neutral lateral

(2) rudders - opposite yaw

(3) throttles - military power

(4) shoulder harness - locked

No recovery, yaw rate increasing (1) lateral stick - in direction of yaw

Engine Stall (1) unload aircraft

(2) throttles - retard both to IDLE

(3) throttle of stalled engine - OFF

If you have any questions, ask them now. You now see the zero signal on the screen.

(The tape now displayed the zero signal and proceeded with the sequence of events as described.)

APPENDIX F

TESTING PROCEDURES

PRE-START CHECKS

1. CPT - ON, 12 VDC to Controls ON, 12 VDC ON-OFF ON
2. X-Y DISPLAY - ON, Intensity set, pip centered
3. Oscilloscope - ON, Intensity set, pip centered
4. Tape Deck - ON, slow speed, counter reading of 800
5. Analog Computer - ON, Reset position
6. 8-Track Recorder - ON, STOP position,
7. Start aircraft, take-off, raise gear, stabilize at 300 KCAS, 20,000 feet
8. Fill aircraft with full internal fuel
9. Place throttles at IDLE
10. Spin Control Box-Power ON, Switches 5, 6 ON, Timer set to zero.
11. Place CPT in FREEZE

TEST PROCEDURES

1. Pilot in cockpit with headphones on
2. Extinguish overhead lighting and secure door to laboratory
3. 8-Track Recorder - ON, 5mm/sec, "÷ 100" activated, Label recording paper with Test Run No.
4. Place CPT in RUN mode
5. Start tape deck
6. Display spin indicator signals as taped briefing describes them.
7. After display of indicator signals, put spin control box

power ON, set switches 5, 6 ON, set Timer to zero, select LEFT direction, switches A, B, C OFF.

8. Place analog computer in operate mode as each tracking task commences, and place it in reset mode during each rest period.

9. During test sequence, deactivate "÷ 100" switch on 8-track Recorder.

10. Monitor control deflections and when lateral and longitudinal controls have been held at maximum deflection, start the departure/spin sequence.

11. Departure/Spin Sequence

    a. Switch A - ON

    b. Switch B - ON, 3 seconds after A

    c. Switch C - ON, 9 seconds after B

12. Stop Test, place CPT in FREEZE.

APPENDIX G

BRIEFING OUTLINE

I. Purpose of Project

   A. Background on the problem

   B. Theory and purpose of spin indicator system

II. Objectives

   A. Measure time required for pilot to respond to:

      1. Departure indications

      2. Spin indications

      3. Stalled engine indications

   B. Measure incorrect/inadequate responses

III. Spin Indicator

   A. Location

   B. Signals

      1. Right departure - green flashing arrow

      2. Right spin - green solid arrow

      3. Left departure - red flashing arrow

      4. Left spin - red flashing arrow

      5. Right engine stall - red light below green arrow

      6. Left engine stall - red light below red arrow

IV. Cockpit Briefing

   A. Inoperative gages (left EGT, left F/F)

   B. Stationary gages (attitude, needle/ball, BDHI)

   C. Gages which would not vary during experiment (A/S altimeter, AOA)

   D. Throttles at IDLE during trial tracking tasks

   E. Throttles at MAX A/B during test sequence

V. Tracking TASK

A. Plotter position (cross-hairs)

B. Pip representation of a bogie

C. Tracking Task as simulation of ACM

1. Object of tracking task

2. Technique of keeping bogie centered on screen

3. Example

D. Sequence of Events and Departure/Spin situation

VI F-14 NATOPS Procedures (for upright, flat condition)

A. Departure

B. Spin

C. Stalled Engine

VII. Miscellaneous

A. Lost Signal (pip)

B. Zero position of stick in dead-band

C. Trim (stick and rudder)

D. Answer questions

APPENDIX H

SPIN INDICATOR RESPONSE

PROJECT INTERVIEW QUESTIONNAIRE

Test Run No. ____________
Date ____________

Name ____________________________________

Rank ____________________________________

Duty Station ____________________________

Designator ______________________________

Warfare Specilaty _______________________

Total pilot hours _______________________

Total first pilot hours _________________

Latest aircraft model flown __________________________

Hours in latest model flown __________________________

Hours in last year ___________________________________

Current in what types of aircraft at present __________________________

Have you ever had spin training? YES/NO When? ____________________

Type Simulator ____________

____

Type aircraft ____________

____

Was the test indicator better than current instrumentation? ______

Do you recommend this, or something similar, for fleet aircraft?

Comments: ____

____

____

____

____

APPENDIX I

DATA ANALYSIS FORM

Test Run Number ______________

1. Departure Response

   a. Time to attain correct departure controls totally.................................. __________

   b. Time to attain full forward stick.......... __________

   c. Time to attain neutral lateral stick....... __________

   d. Time to retard both throttles to MIL PWR... __________

   e. Time to attain full opposite rudder........ __________

   f. Number of incorrect responses.............. __________

   g. Number of inadequate responses............. __________

2. Stalled Engine Response

   a. Time to attain correct engine stall procedures totally........................ __________

   b. Time to retard both throttles to IDLE PWR.. __________

   c. Time to put stalled engine throttle OFF.... __________

   d. Number of incorrect responses.............. __________

   e. Number of inadequate responses............. __________

3. Spin Response

   a. Time to attain correct spin controls totally.................................. __________

   b. Time to attain full lateral stick.......... __________

   c. Number of incorrect responses.............. __________

   d. Number of inadequate responses............. __________

APPENDIX J

TEST SUBJECT COMMENTS

FAVORABLE

1. "...the arrows seem to be an improvement over a standard turn needle." (VF pilot, 1200 hrs.)

2. "...light indicator is quite superior, ...because of simplicity of interpretation." (VS pilot, 1300 hrs.)

3. "Test indicator better than turn needle...representation for a stalled engine is outstanding, and this one was very easy to respond to." (VF pilot, 3000 hrs.)

4. "I like the arrow to tell me direction of rotation." (VA pilot, 2100 hrs.)

5. "I feel that <u>any</u> device which correlates info from several instruments necessary to diagnose a departure/ spin (i.e., AOA, airspeed, needle/ball, etc.) would significantly reduce pilot reaction time. He would not then be required to go through the inductive process of: 1) am I spinning? 2) which way? etc. A GOOD DEAL!" (VA pilot 2300 hrs.)

6. "By multiple repetition on indicator box, immediate departure/spin recognition and recovery controls would become ingrained, tremendously reducing response time." (VF pilot, 2000 hrs.)

7. "Very clear indicator of spin direction and engine loss. Easy to read!! Very little confusion." (HS pilot 1700 hrs.)

8. "...a trainer is the only means to bring pilot efficiency into the acceptable survivability range. The first time through this simulator I was very uncertain of my actions, but the second time I was very comfortable in the exercise. I can see how this experiment would be good for fleet pilots." (HS pilot, 900 hrs.)

9. "Even though unfamiliar with the aircraft cockpit, controls, etc., the test indicator readily identified what corrective action was necessary." (Army pilot, 1000 hrs.)

10. "(1) Engine stall indicating system should be put into F-14 ASAP. Would recommend "stall" warning lights colocated with "fire" warning lights - both are serious engine problems requiring a quick "which one?" decision; also, the initial steps of each procedure are similar. (2) Do not believe that the arrow direction indicator is anything more than a glorified turn needle; but an arrow is a much easier-to-interpret display of information than the rather obscure and small turn needles in current use. So for no other reason than the display is a quantum leap easier to interpret, I like the arrow system and would recommend its incorporation." (VF pilot, 2700 hrs.)

11. "Flashing arrow cue was timely and effective post-departure." (VA pilot, 3000 hrs.)

UNFAVORABLE

1. "...change over to solid light (spin indication) was not a significant event and was felt to have not registered

immediately with this pilot. Also, engine stall light for left is diluted in effectiveness by color similarity (red) with arrow (red)." (VA pilot, 3000 hrs.)

2. "However, the indicator encourages an immediate response in all situations and might be overwhelming." (VF pilot, 3000 hrs.)

APPENDIX K

TABLE I

SEQUENCE OF EVENTS ON THE TEST

PROCEDURES TAPE RECORDING

Tape Deck Counter Reading	Evolution
777	Start of Zero Signal
800	Voice Briefing Commences
882	Display of Zero Signal (60 sec.)
895	Vertical Trial Tracking Task (45 sec.)
907	Rest period with Zero Signal (15 sec.)
912	Horizontal Trial Tracking Task (45 sec.)
923	Rest period with Zero Signal (15 sec.)
930	Two Axis Trial Tracking Task (75 sec.)
951	Rest period with Zero Signal (45 sec.)
967	ACM Test Sequence (3.5 min.)
1055	End of Test
1077	End of Signal

TABLE II

EIGHT-TRACK STRIP CHART

RECORDING SYSTEM CHANNELIZATION

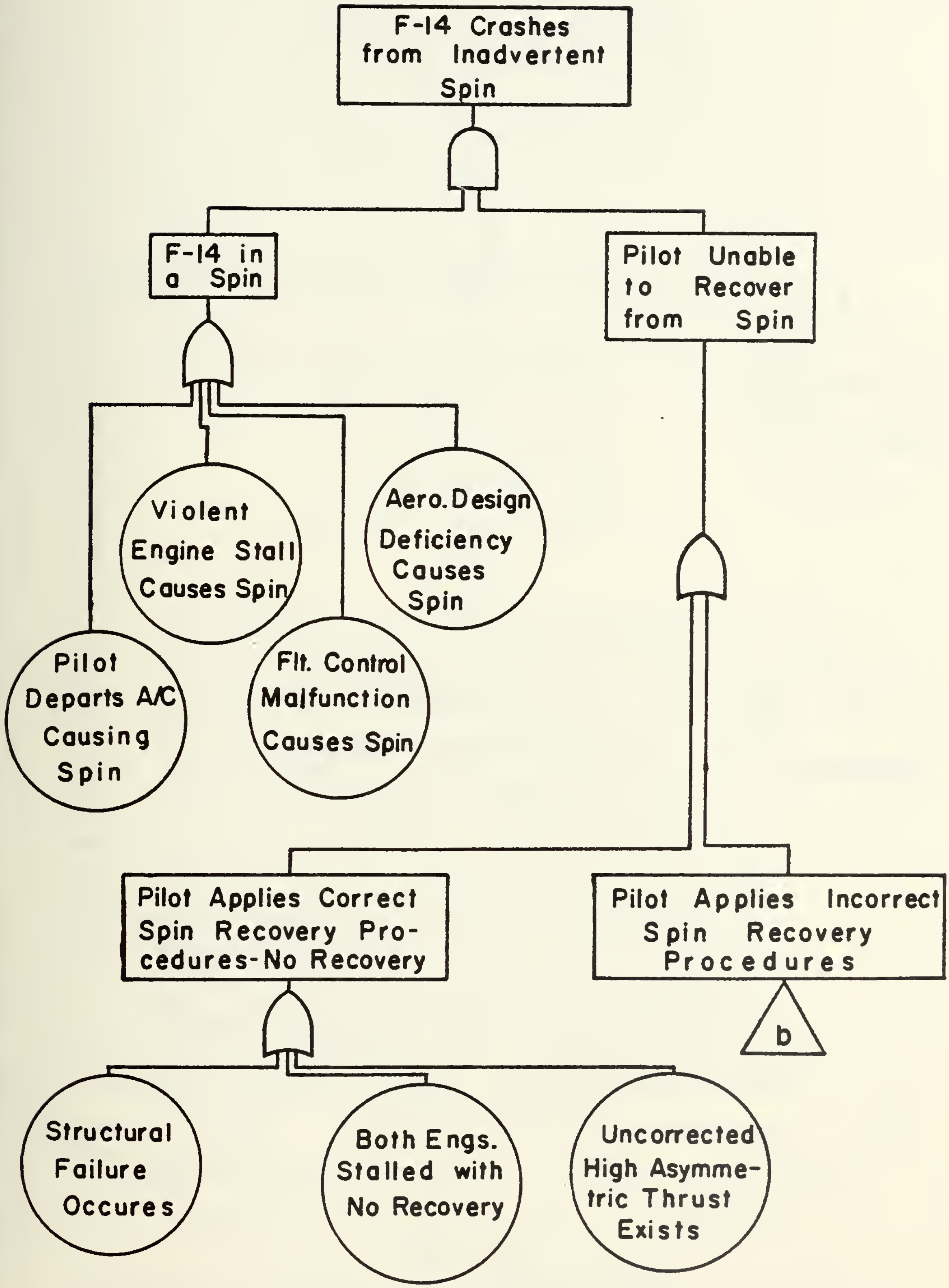
CHANNEL	SUBJECT
1	Departure Signal (Output A)
2	Engine Stall Signal (Output B)
3	Spin Signal (Output C)
4	Longitudinal Stick Position
5	Lateral Stick Position
6	Rudder Position
7	Left Throttle Position
8	Right Throttle Position

TABLE III

TEST SUBJECT CATEGORY CLASSIFICATION

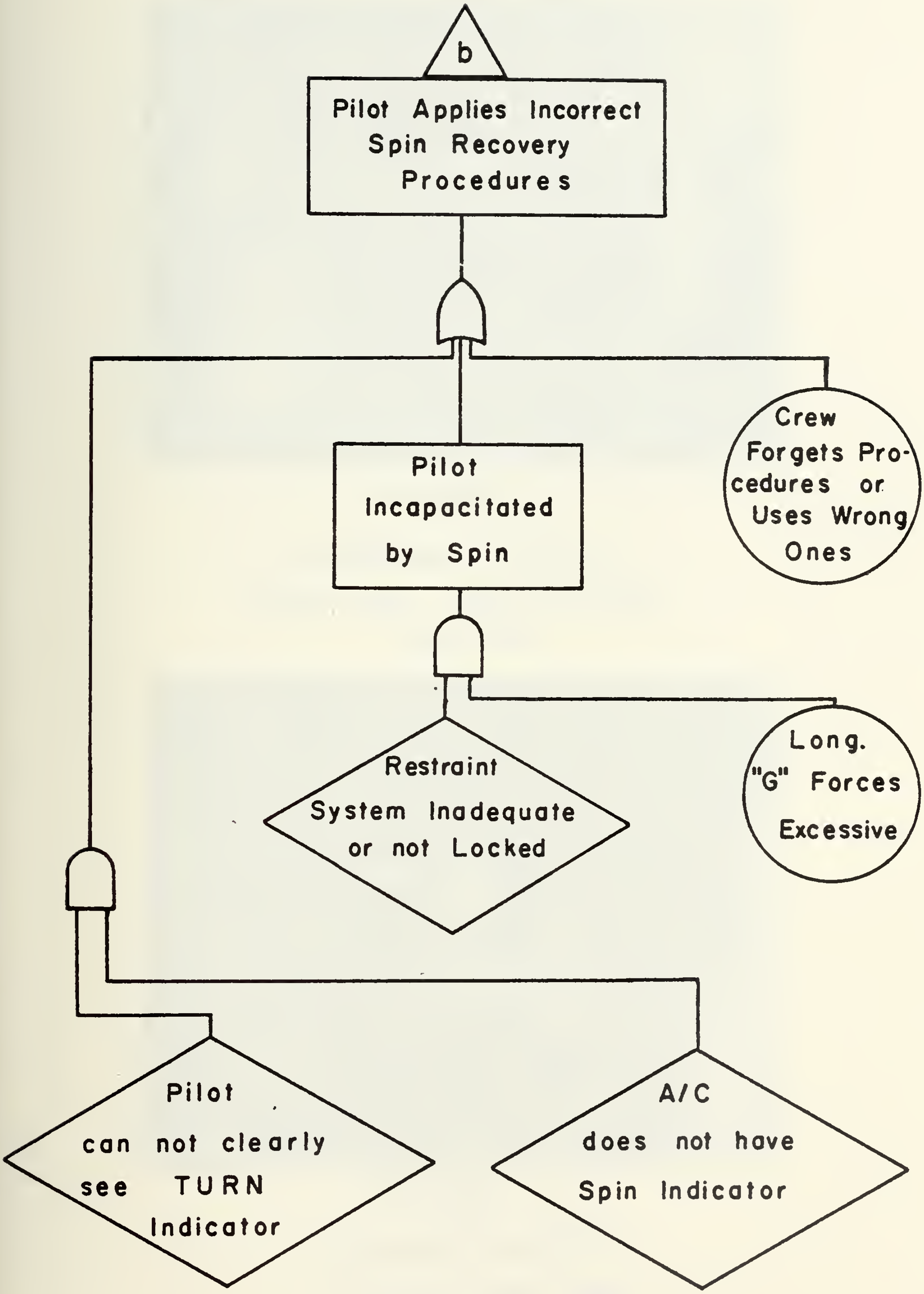
Category Designation	Classification	Subjects (Test Run Numbers)	Number of Subjects
T	TACAIR Pilots (VF, VA)	102,103,105,201,202, 204,302,309,312	9
TP	Proficient TACAIR Pilots	102,103,105,201,204, 312	6
TN	Non-Proficient TACAIR Pilots	202,302,309	3
P	Proficient Pilots of all communities	102,103,104,105,201, 204,305,312	8
N	Non-Proficient Pilots of all communities	202,302,303,304,308, 309,313	7
A	All Pilots of all communities	102,103,104,105,201, 202,204,302,303,304, 305,308,309,312,313	15
O	Others (Non-pilots)	203,301,314	3
R	Repeat test subjects of all communities	205,206,306,307,310, 311,315,316,317	9

APPENDIX L



Part (a).

FIGURE I. FAULT TREE ANALYSIS CHART



Part (b).

FIGURE I. FAULT TREE ANALYSIS CHART

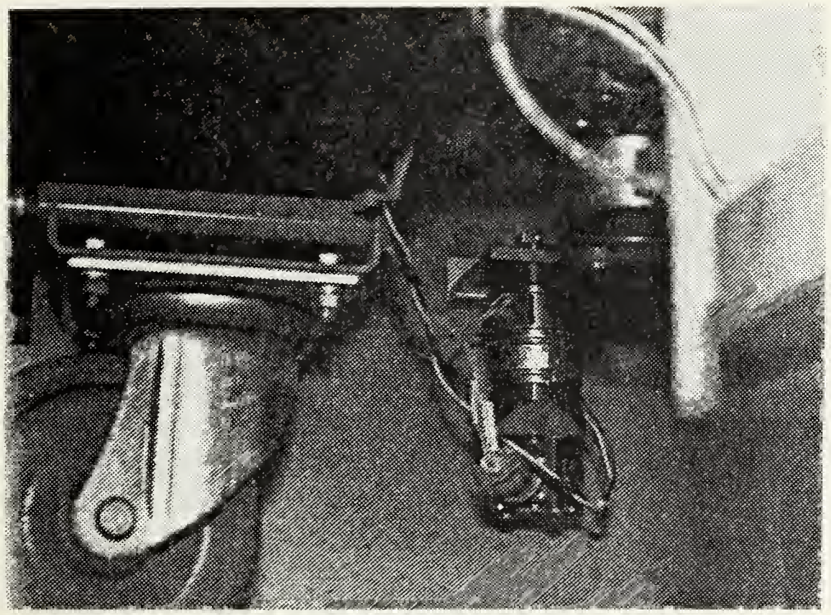


FIGURE 2

LATERAL STICK
POSITION MONITORING
SYSTEM

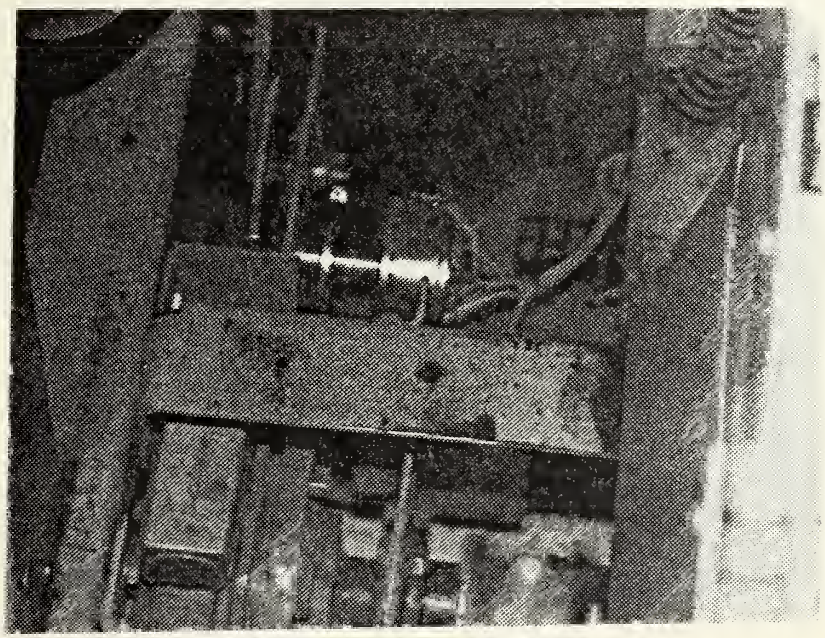


FIGURE 3

LONGITUDINAL
STICK POSITION
MONITORING SYSTEM

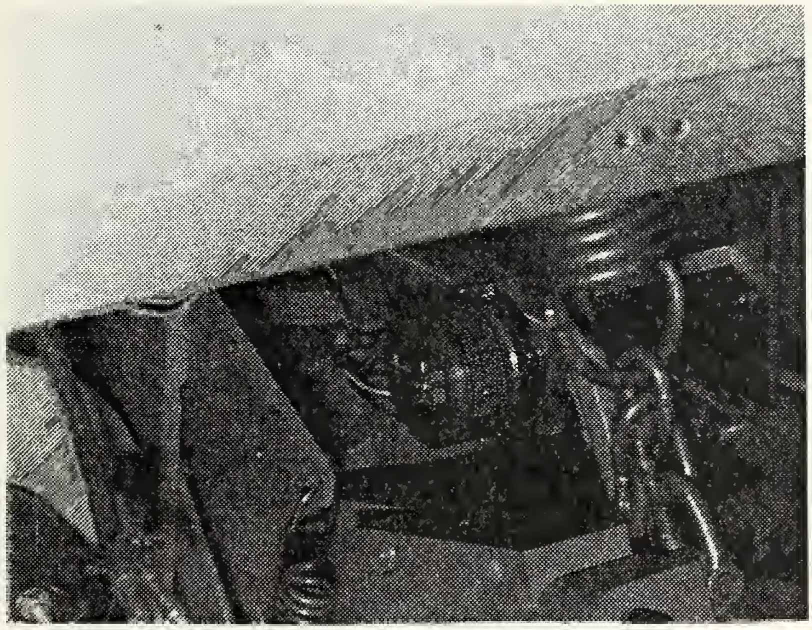


FIGURE 4

RUDDER POSITION
MONITORING
SYSTEM

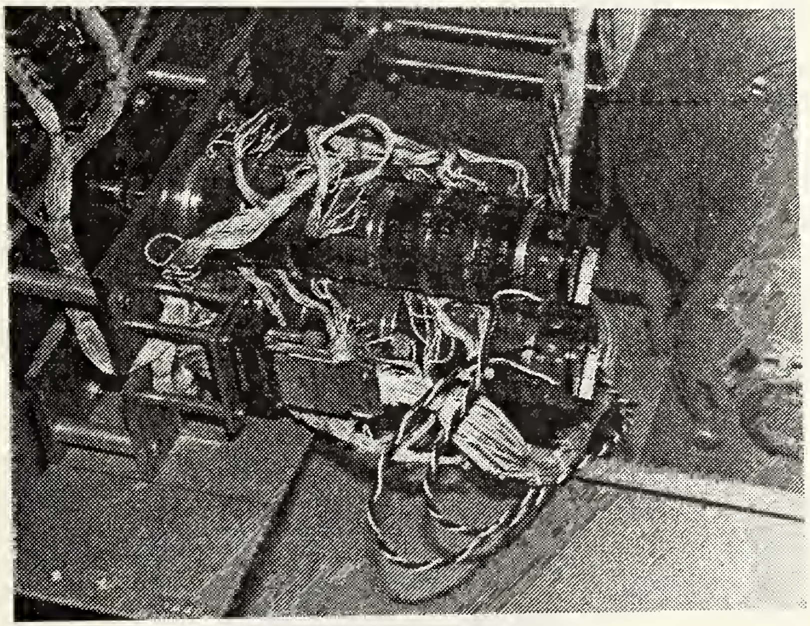


FIGURE 5

THROTTLE POSITION
MONITORING
SYSTEM

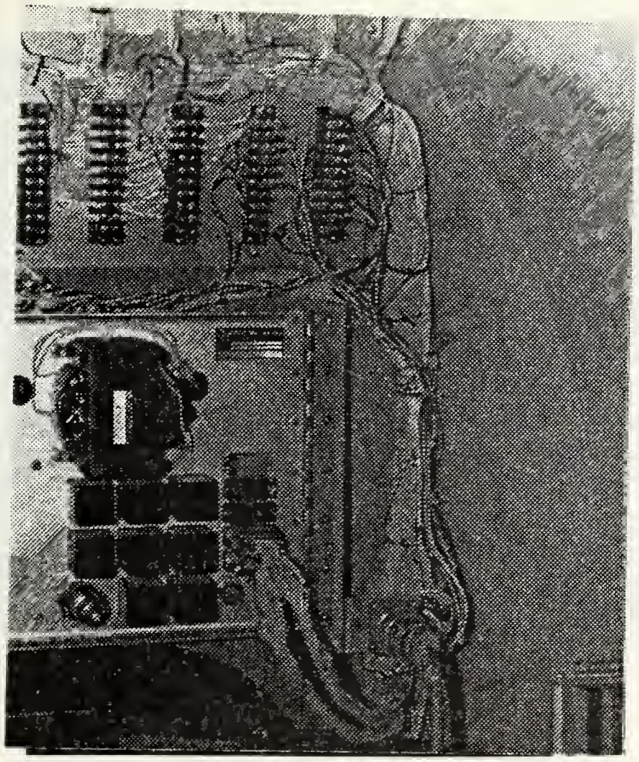


FIGURE 6

TERMINAL BOARDS 19 & 20,
WITH ADDITIONAL WIRING,
PLUG, JACK, AND CABLE

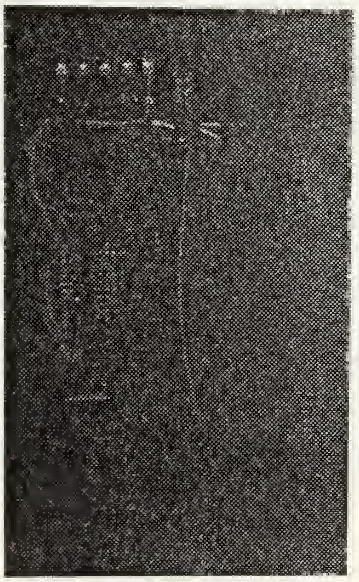


FIGURE 7
INTERIOR VIEW
OF CONTROL PANEL

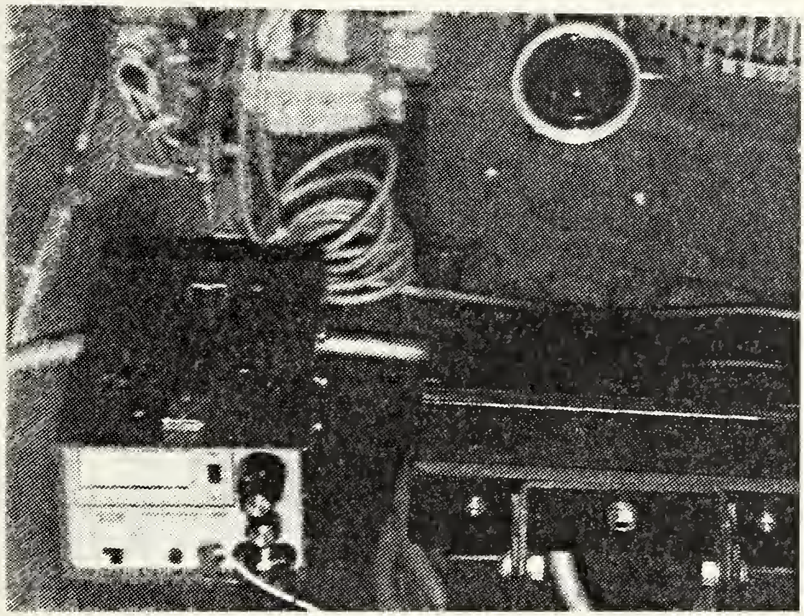


FIGURE 8

VIEW OF ONE PMC

POWER SUPPLY

FIGURE 9

EXTERIOR VIEW

OF CONTROL PANEL

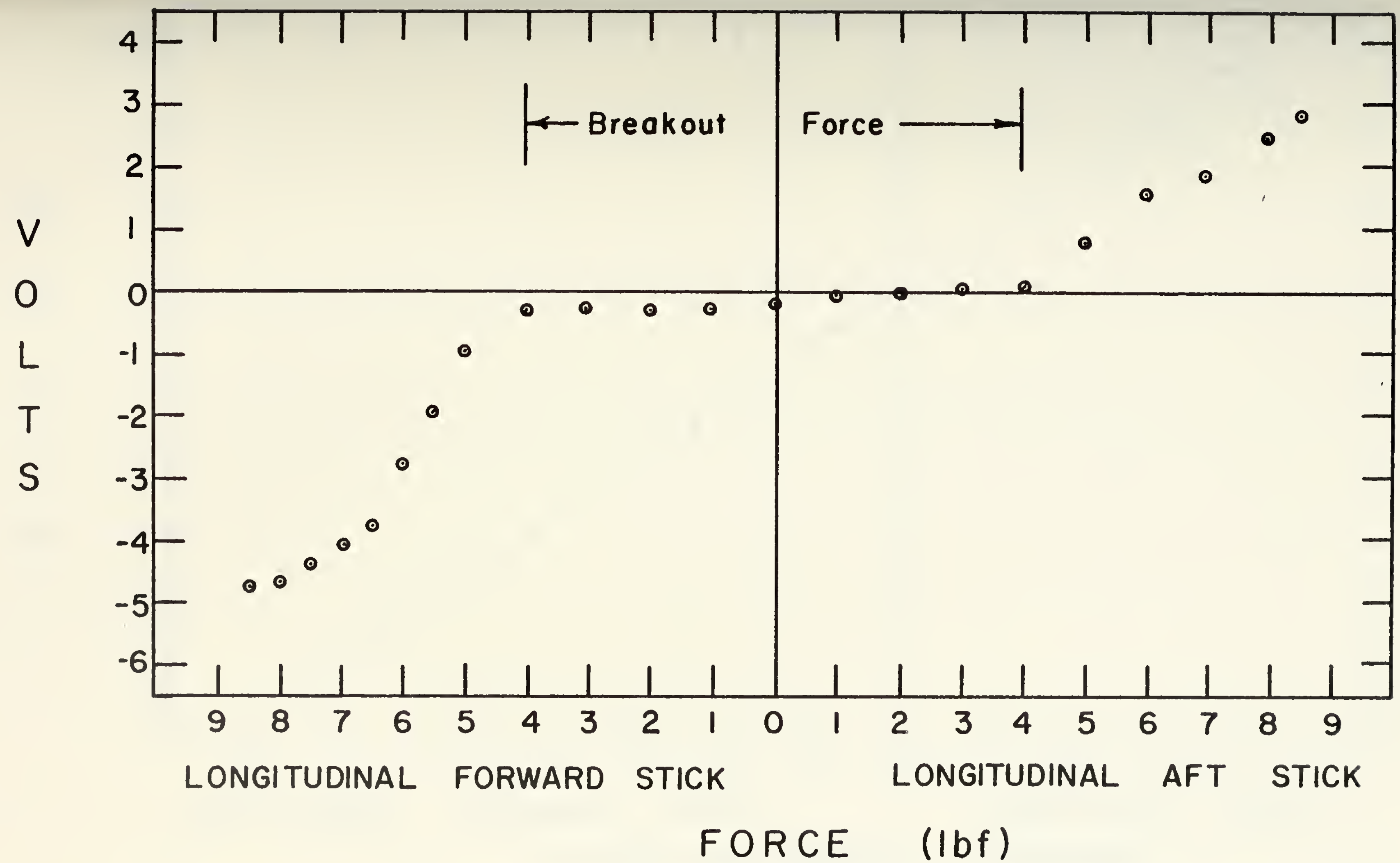


FIGURE 10. OUTPUT VOLTAGE VS. LONGITUDINAL STICK FORCE

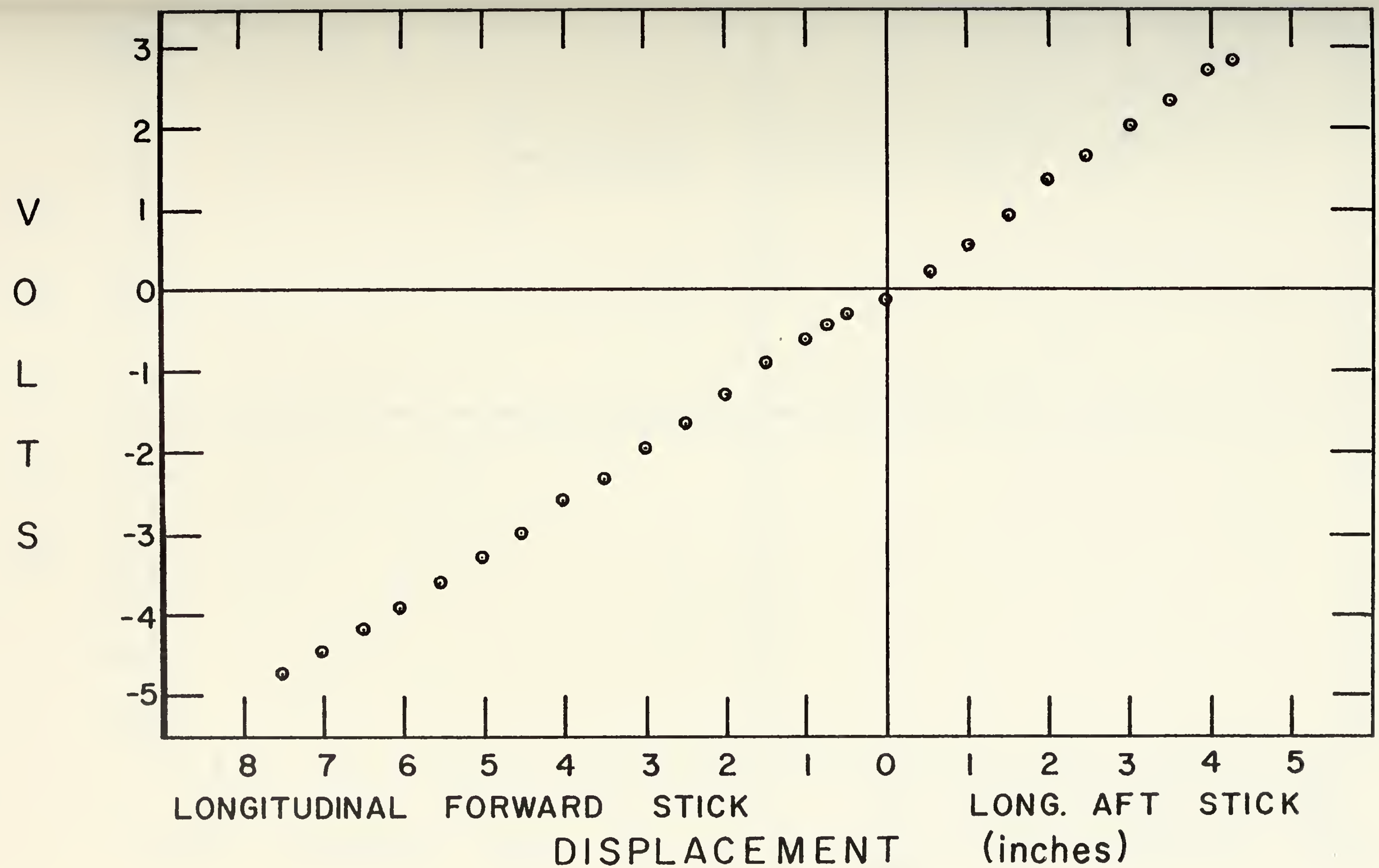


FIGURE II. OUTPUT VOLTAGE VS. LONGITUDINAL STICK DISPLACEMENT

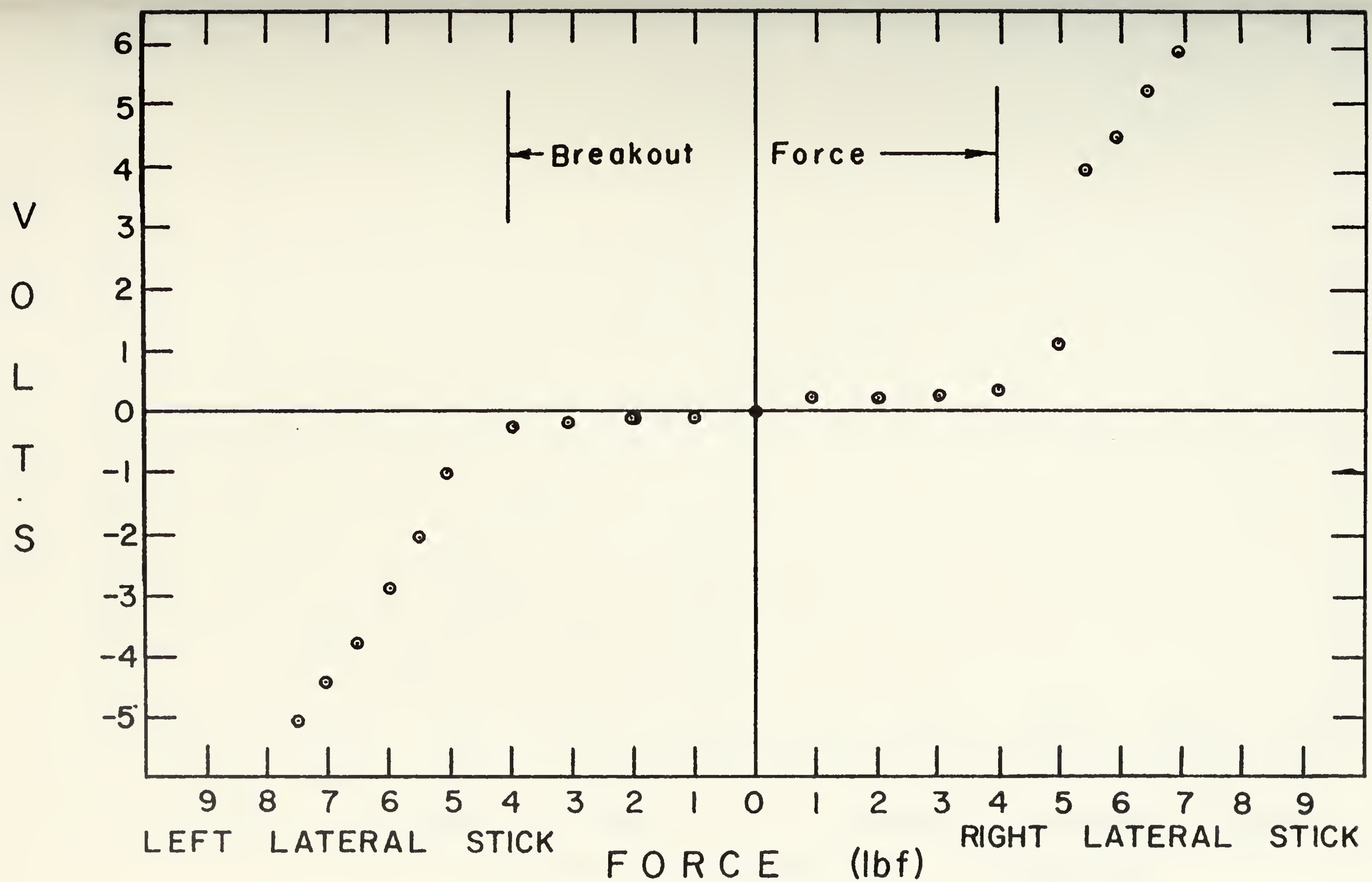


FIGURE 12. OUTPUT VOLTAGE VS. LATERAL STICK FORCE

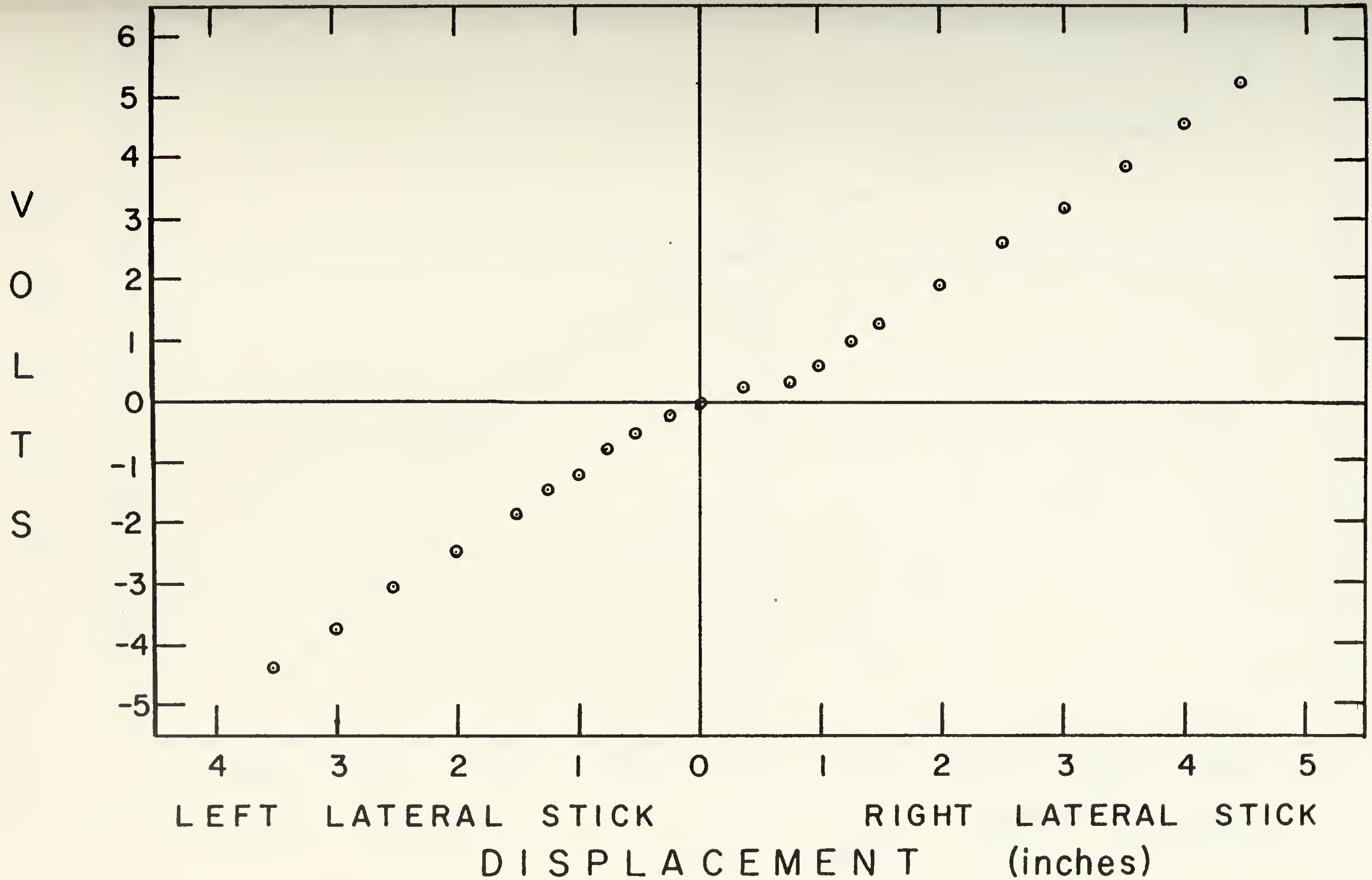


FIGURE 13. OUTPUT VOLTAGE VS. LATERAL STICK DISPLACEMENT

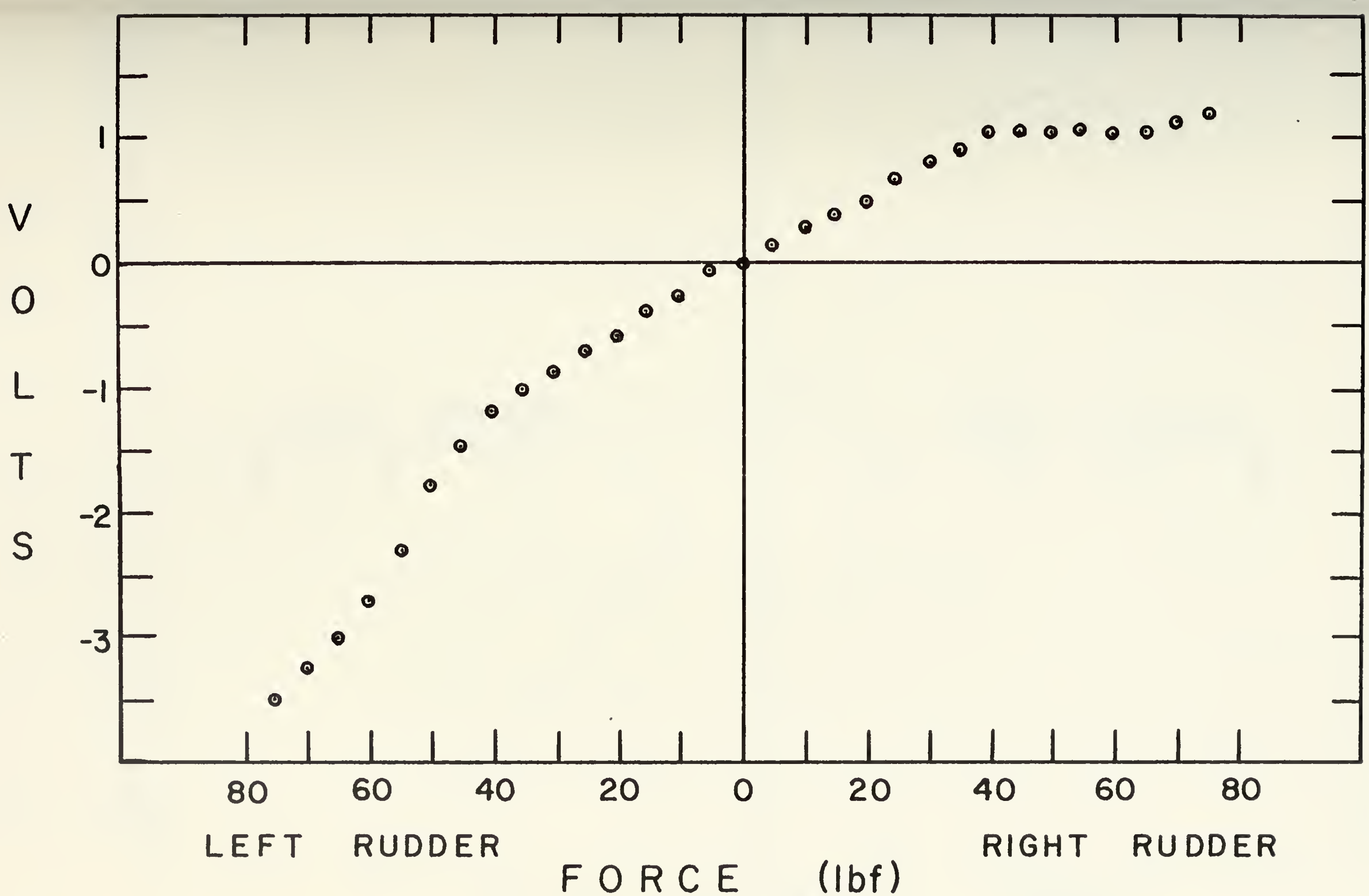


FIGURE 14. OUTPUT VOLTAGE VS. RUDDER FORCE

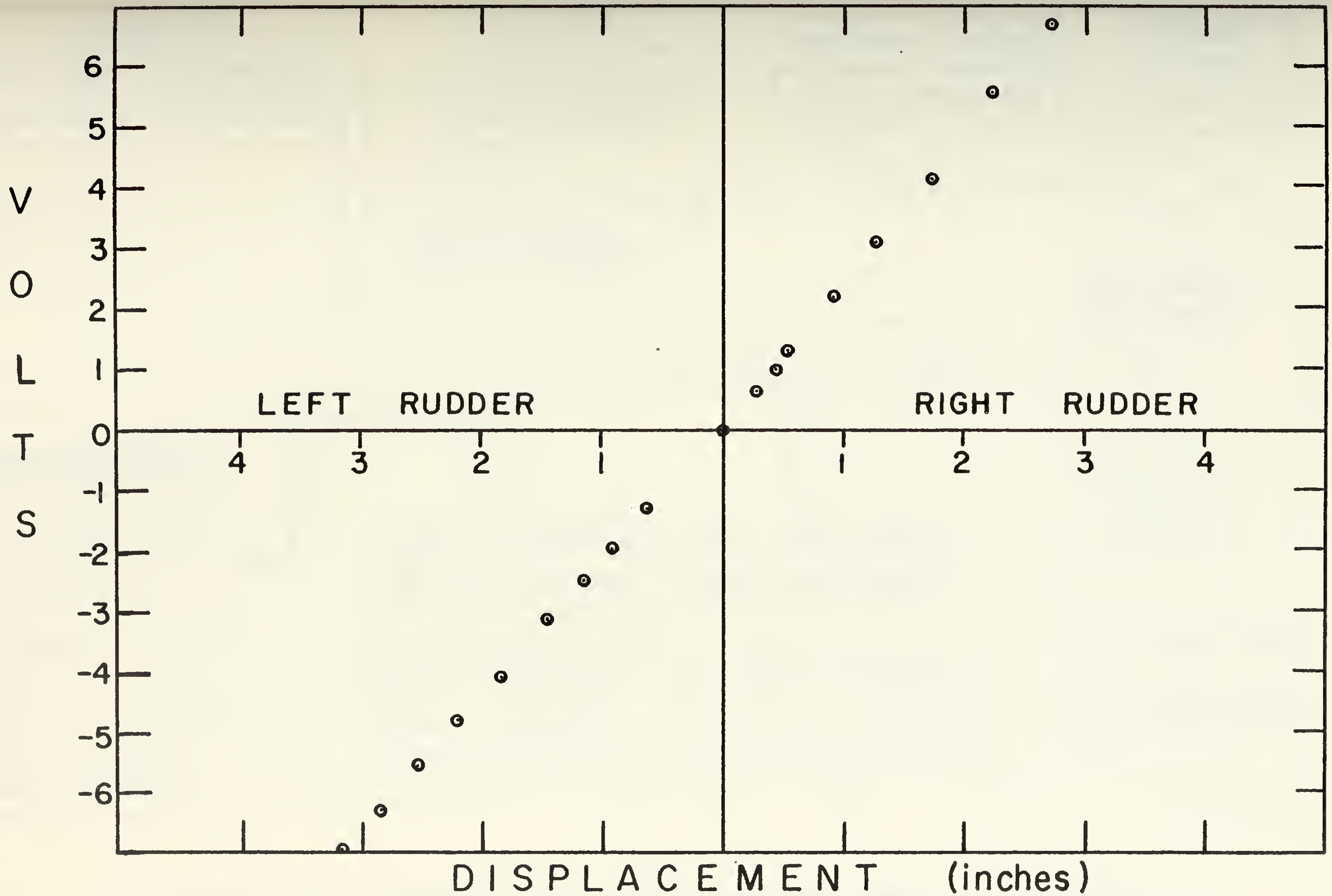


FIGURE 15. OUTPUT VOLTAGE VS. RUDDER DISPLACEMENT

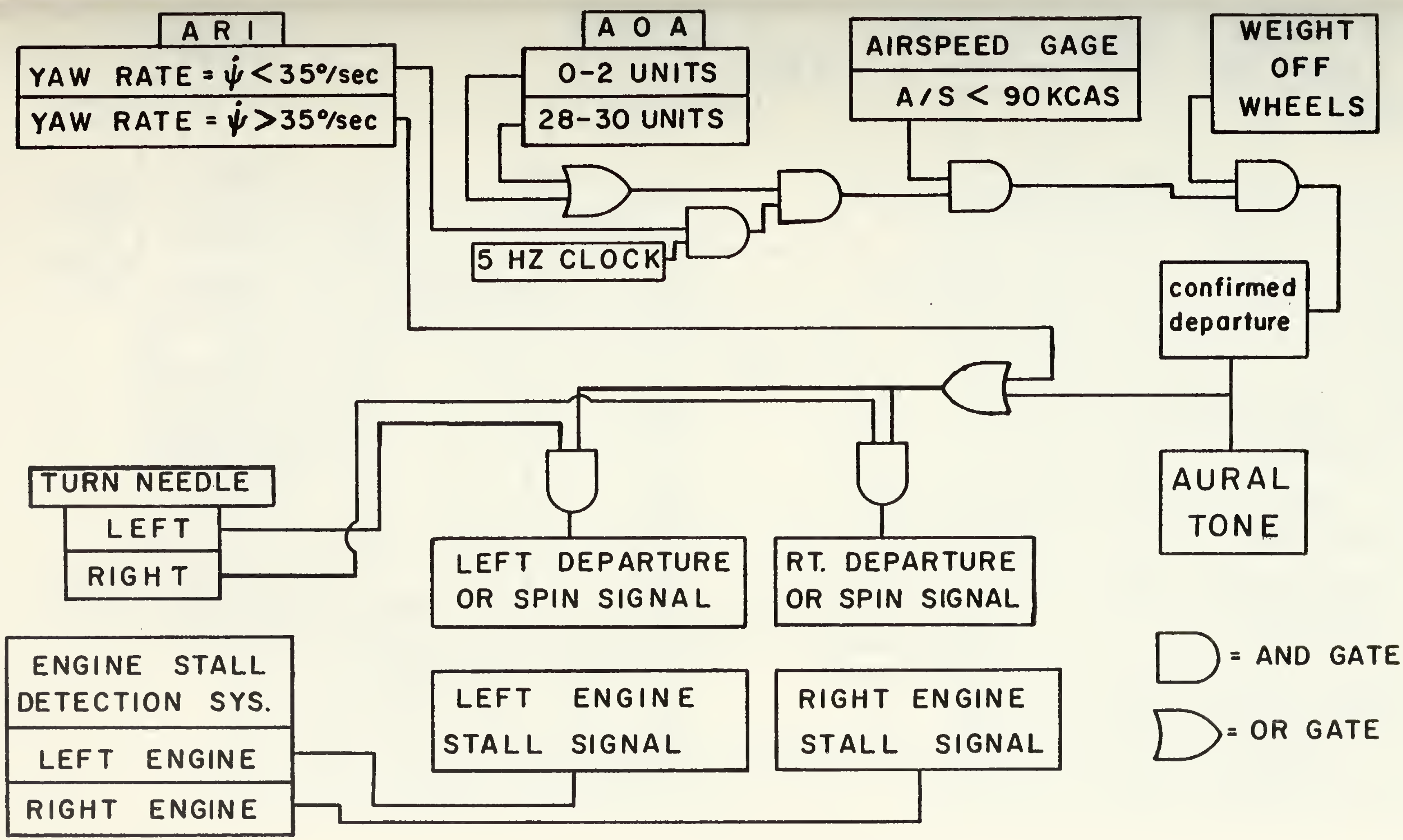


FIGURE 16. CONCEPTUAL DESIGN OF SPIN INDICATOR

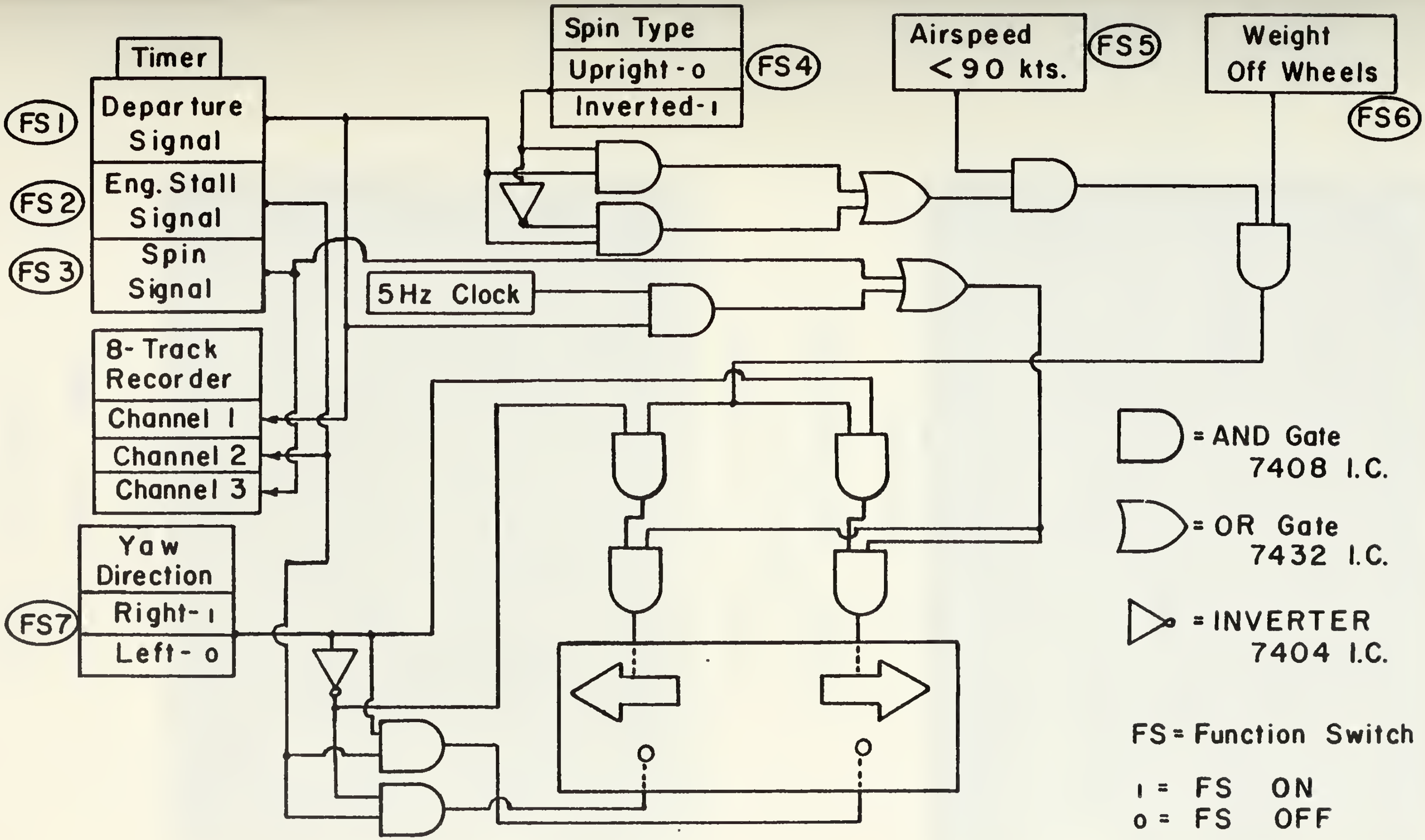


FIGURE 17. HARDWARE CIRCUIT FOR SPIN INDICATOR

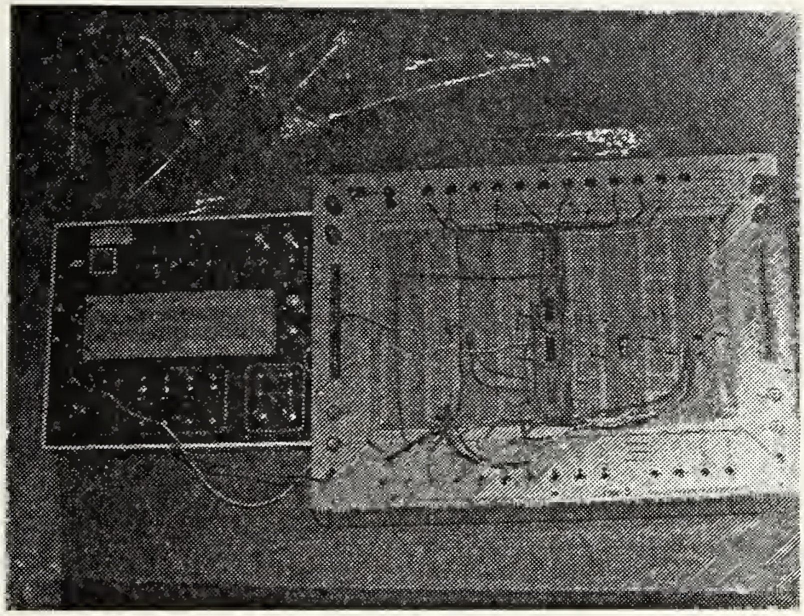


FIGURE 18

BREADBOARD MODEL
OF SPIN
INDICATOR CIRCUIT

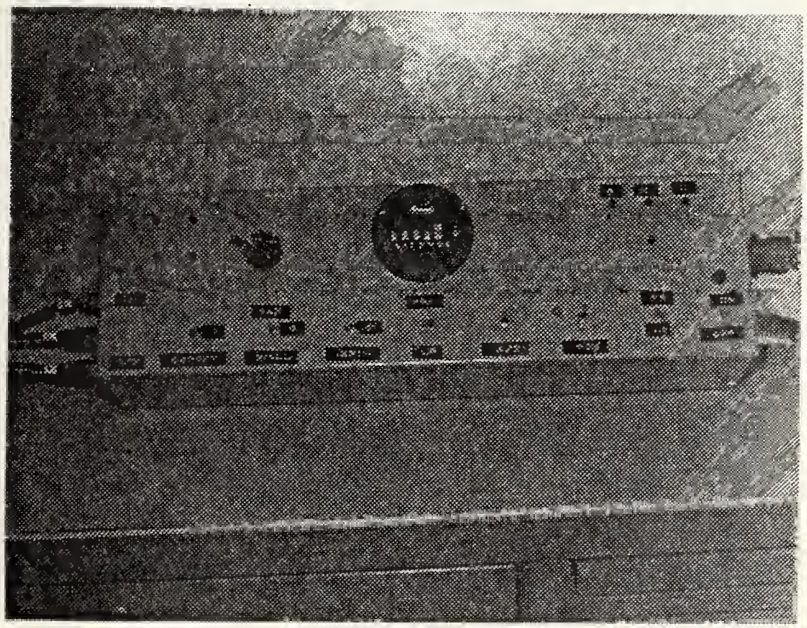


FIGURE 19

SPIN INDICATOR
CONTROL BOX

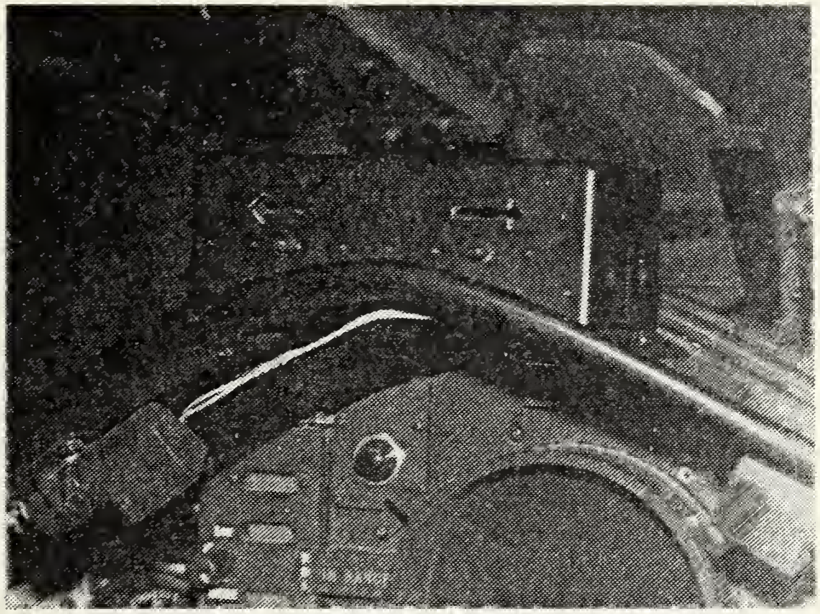


FIGURE 20

SPIN INDICATOR ON
GLARE SHIELD
IN COCKPIT

FIGURE 21

OVERALL VIEW
OF THE FACILITY

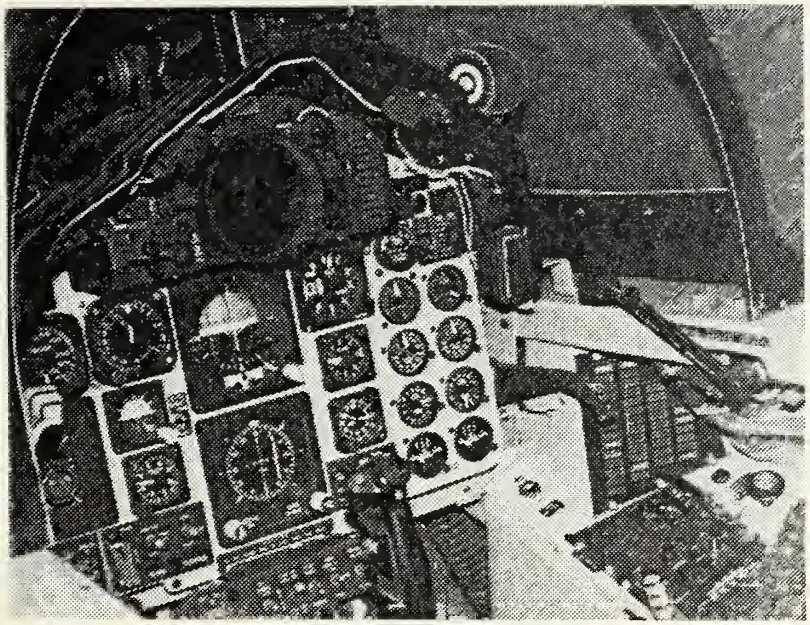


FIGURE 22

INTERIOR VIEW

OF THE COCKPIT

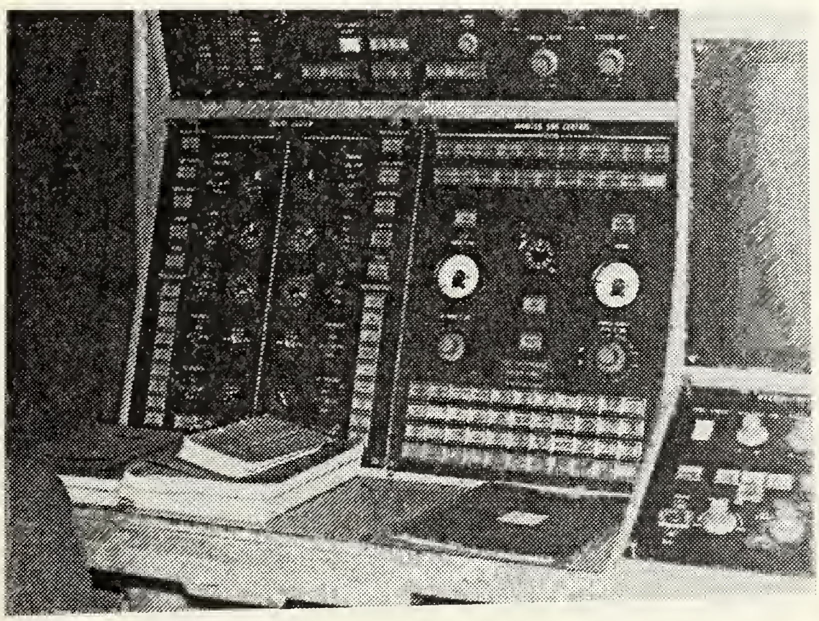


FIGURE 23

CONTROLLER'S

CONSOLE

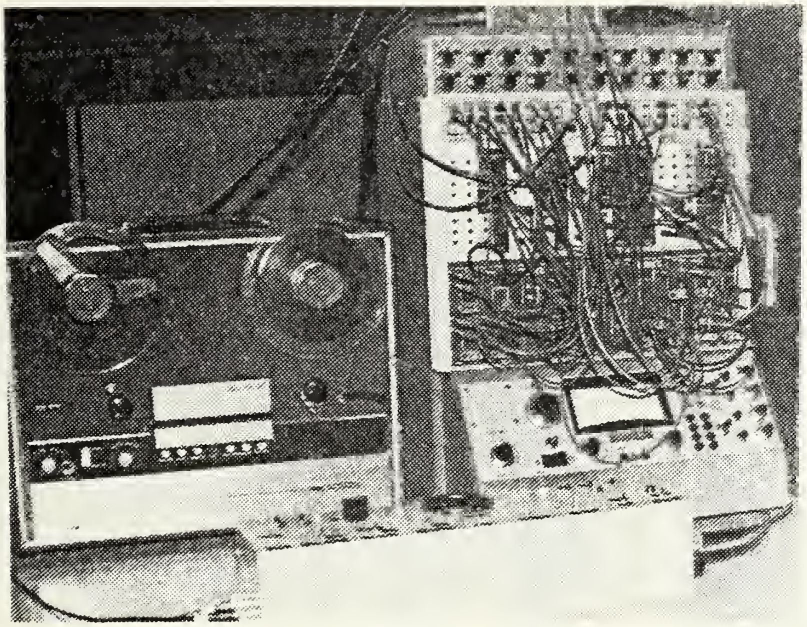


FIGURE 24
THE CONTROL
POSITION

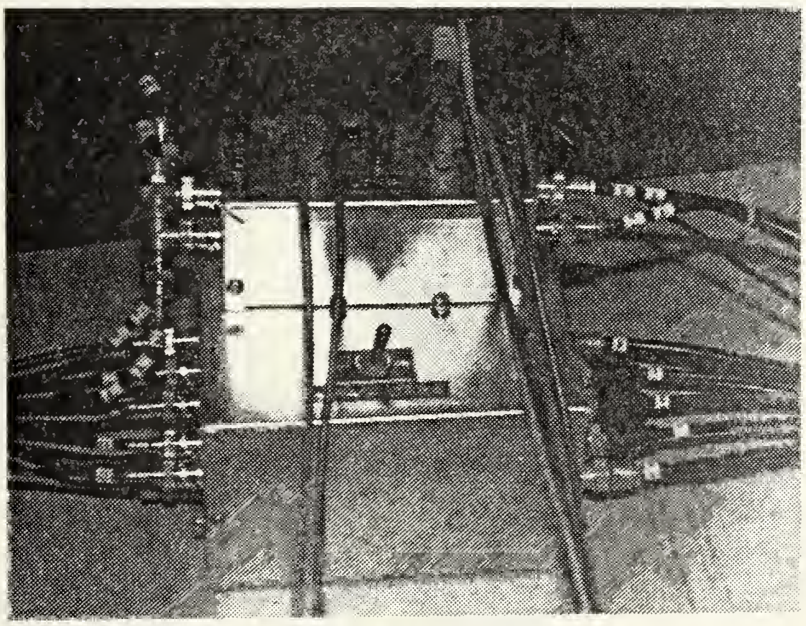


FIGURE 25
THE SIGNAL
CONTROL BOX

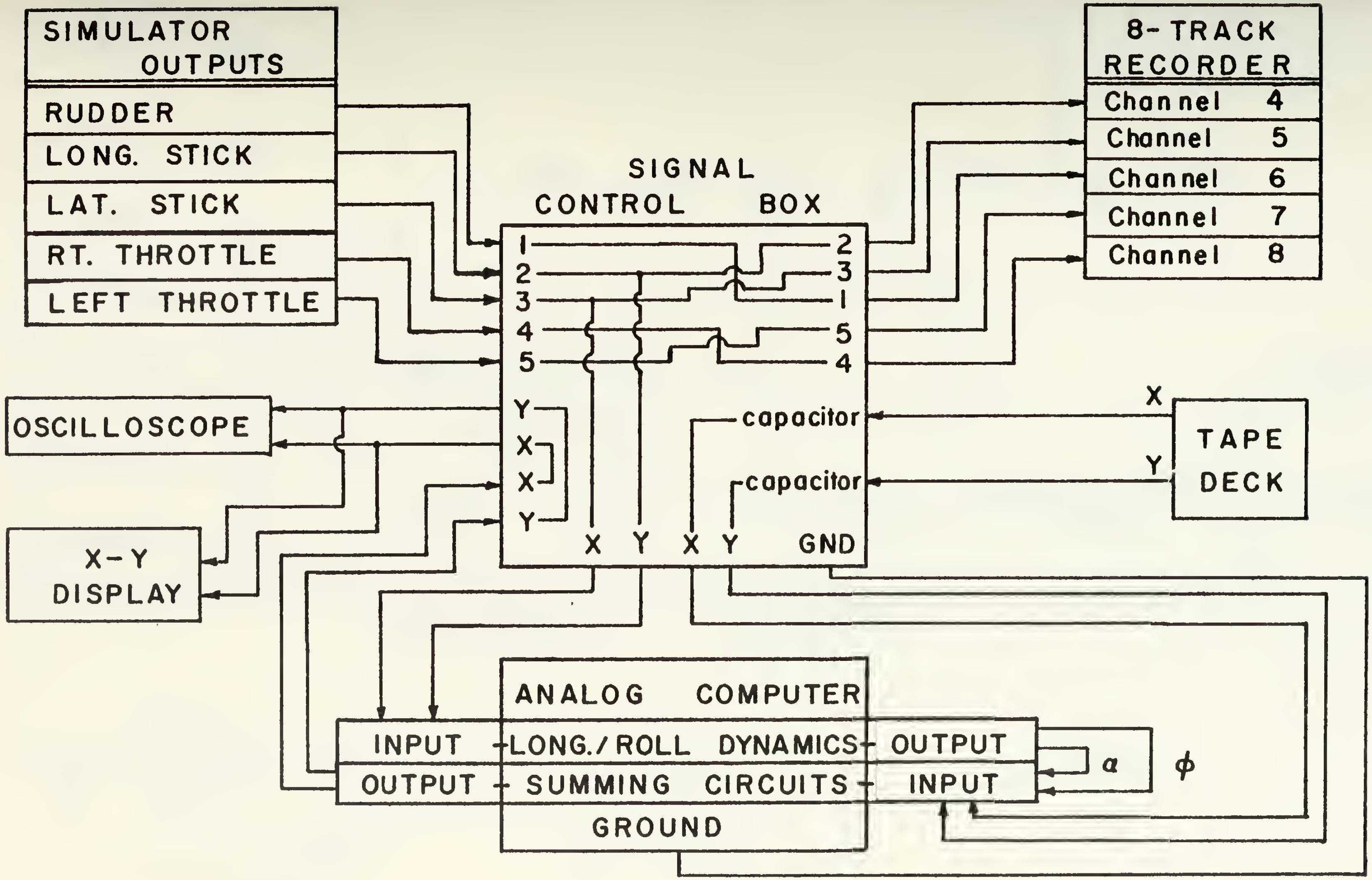
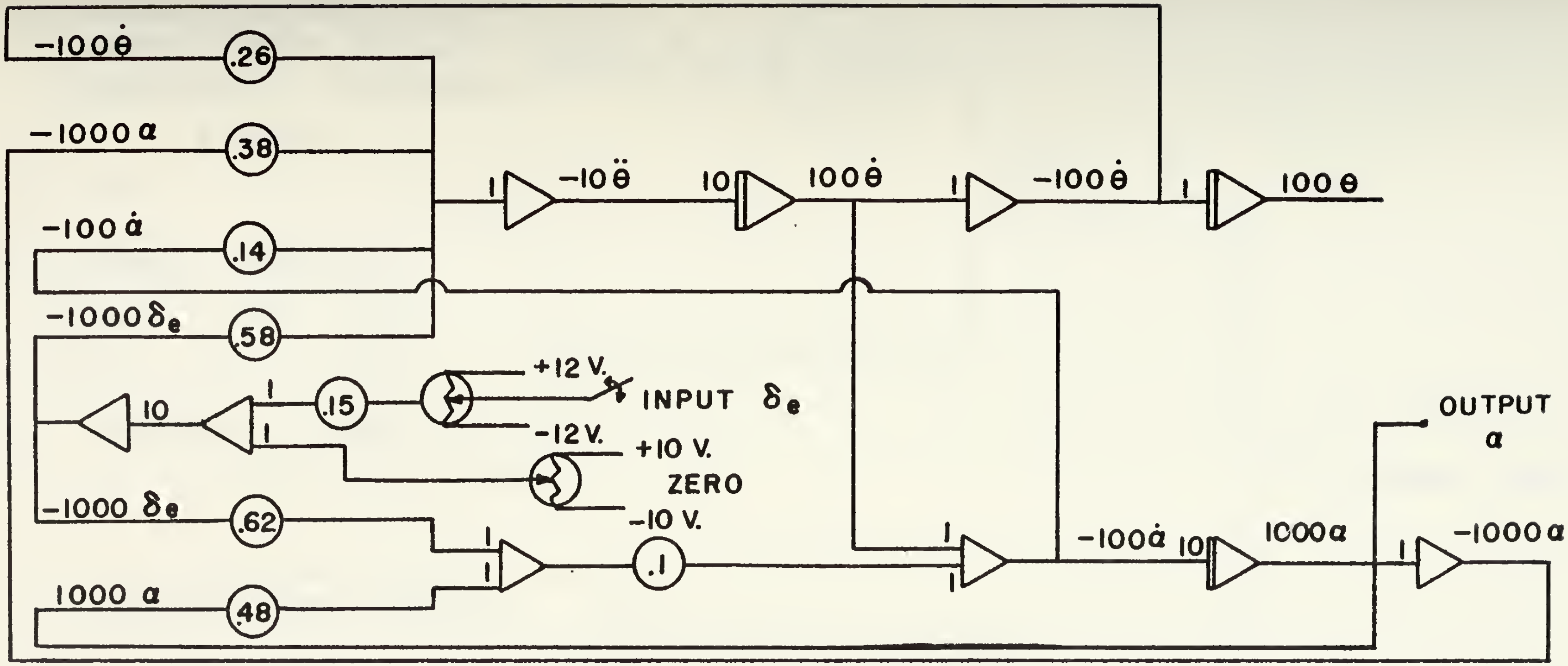
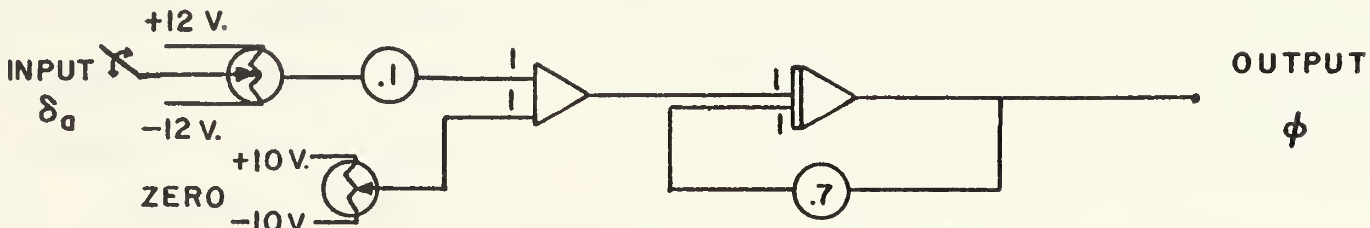


FIGURE 26. SIGNAL CONTROL BOX SYSTEM INTERFACE



LONGITUDINAL DYNAMICS



ROLL DYNAMICS

FIGURE 27. ANALOG COMPUTER CIRCUITS

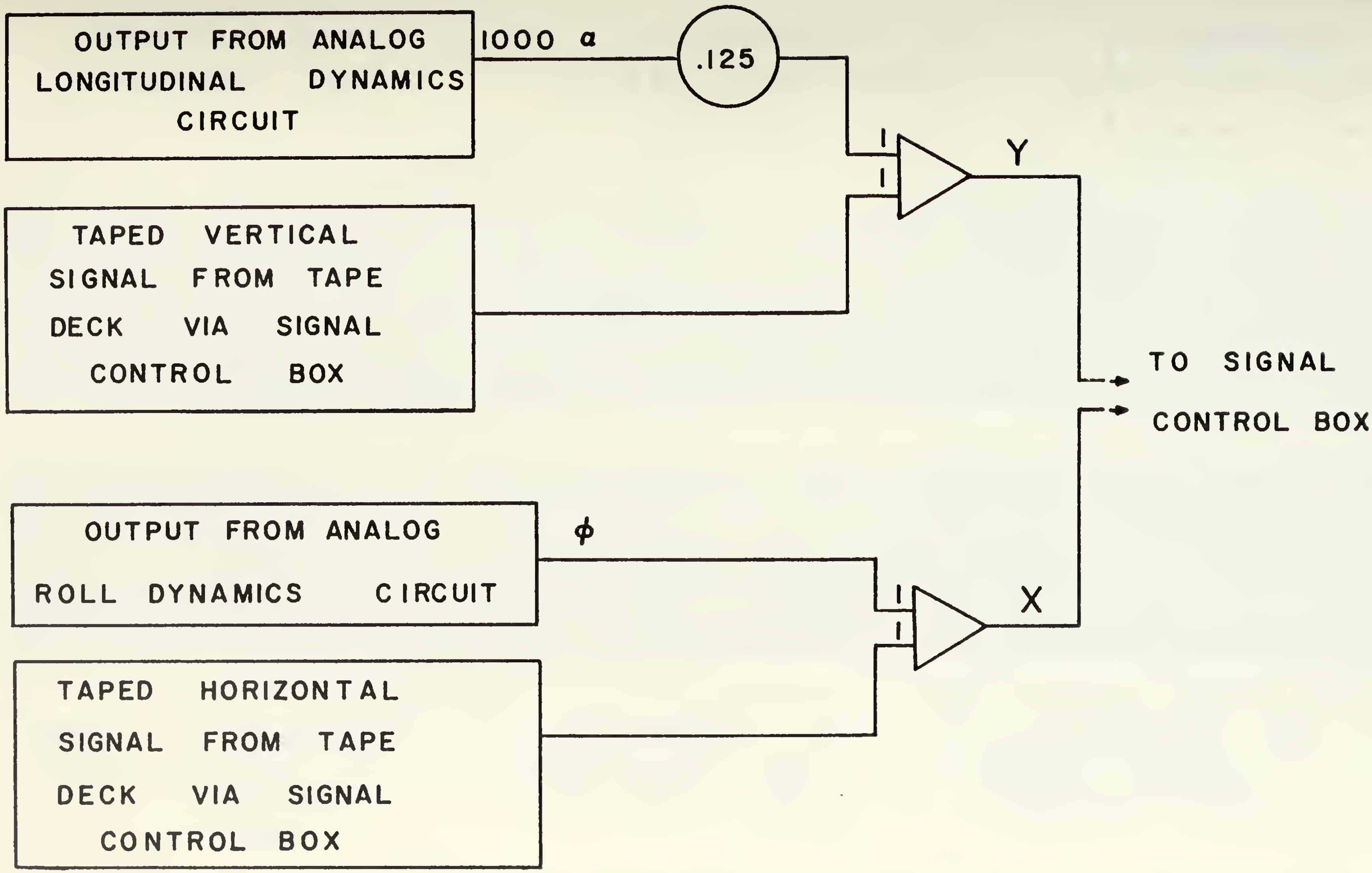


FIGURE 28. VERTICAL & HORIZONTAL SUMMING CIRCUITS

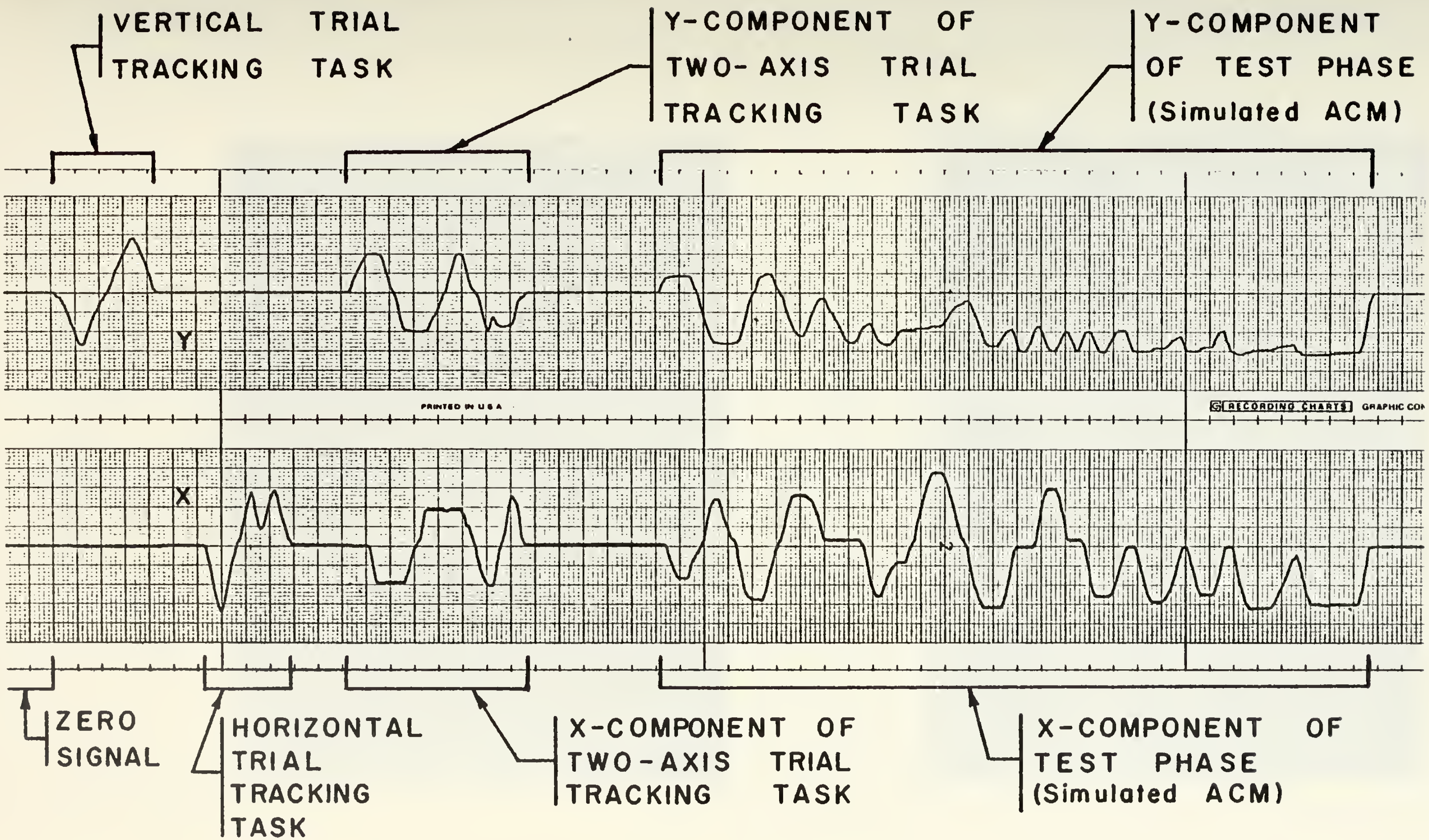


FIGURE 29. REPRODUCTION OF TAPED SIGNAL

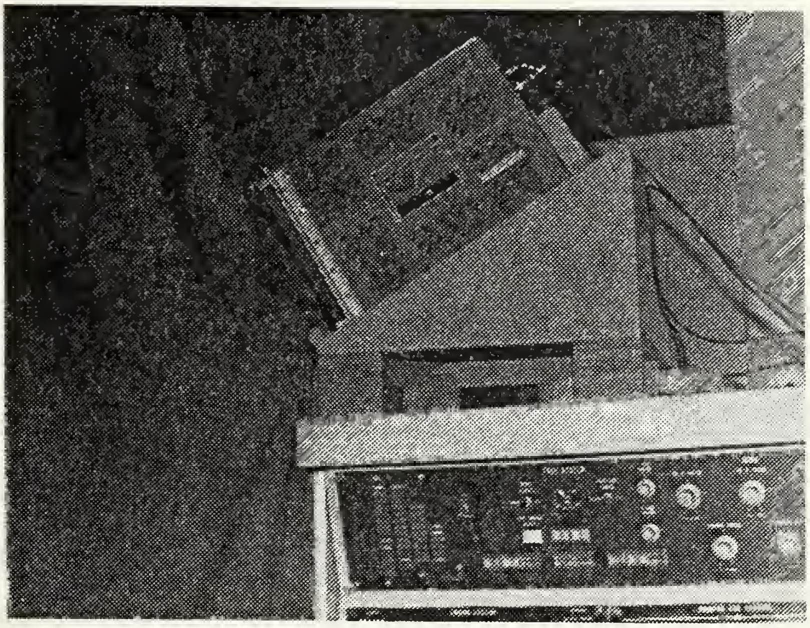


FIGURE 30

SIDE VIEW OF

X-Y DISPLAY

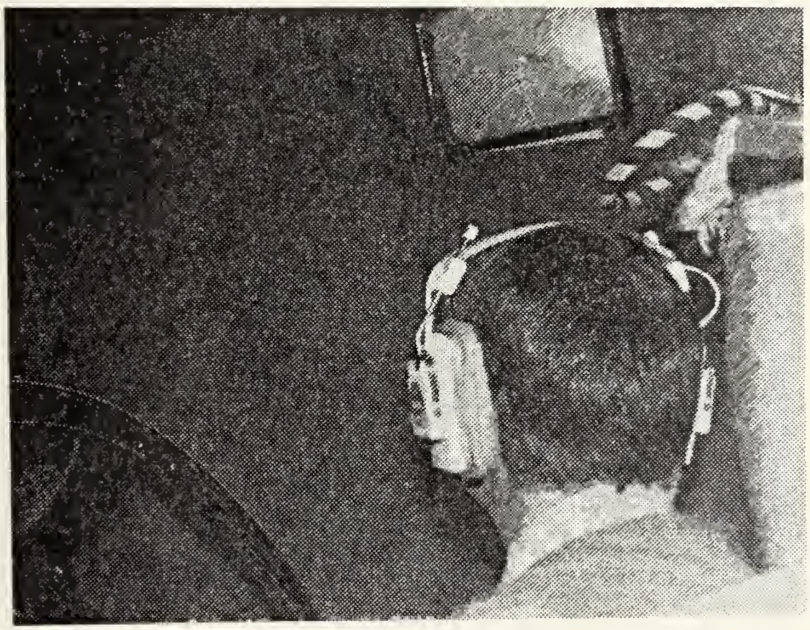


FIGURE 31

FRONTAL VIEW OF

X-Y DISPLAY

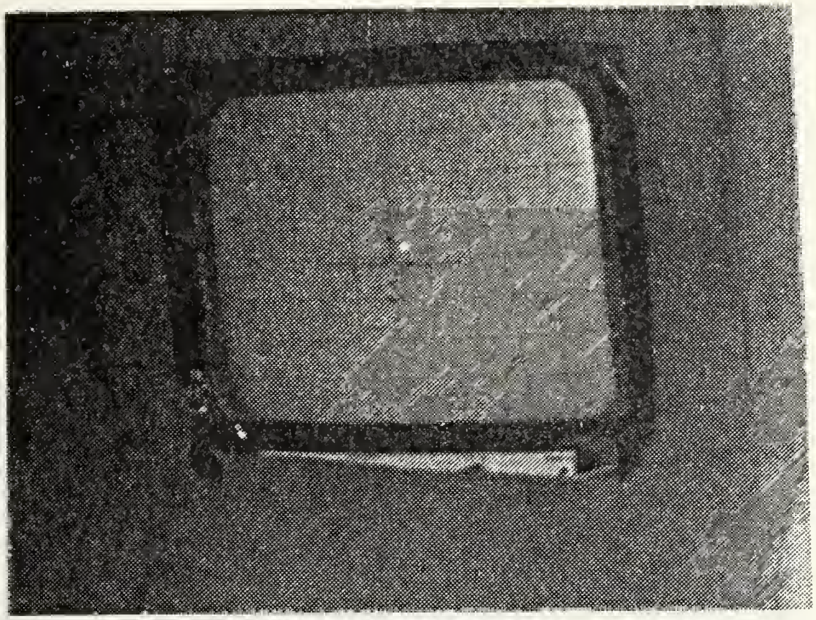


FIGURE 32

CLOSE-UP VIEW
OF X-Y DISPLAY
WITH CROSS-HAIRS AND PIP

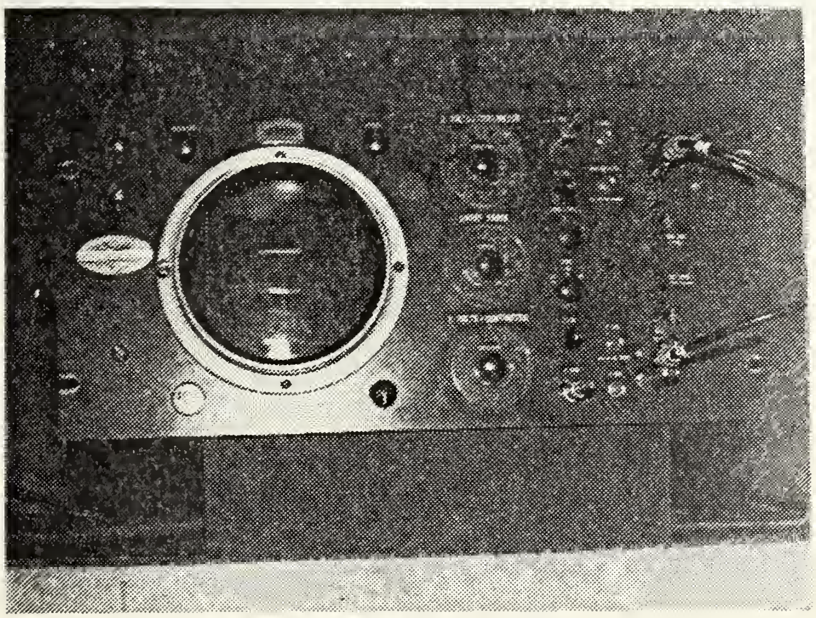


FIGURE 33

CLOSE-UP VIEW
OF OSCILLOSCOPE

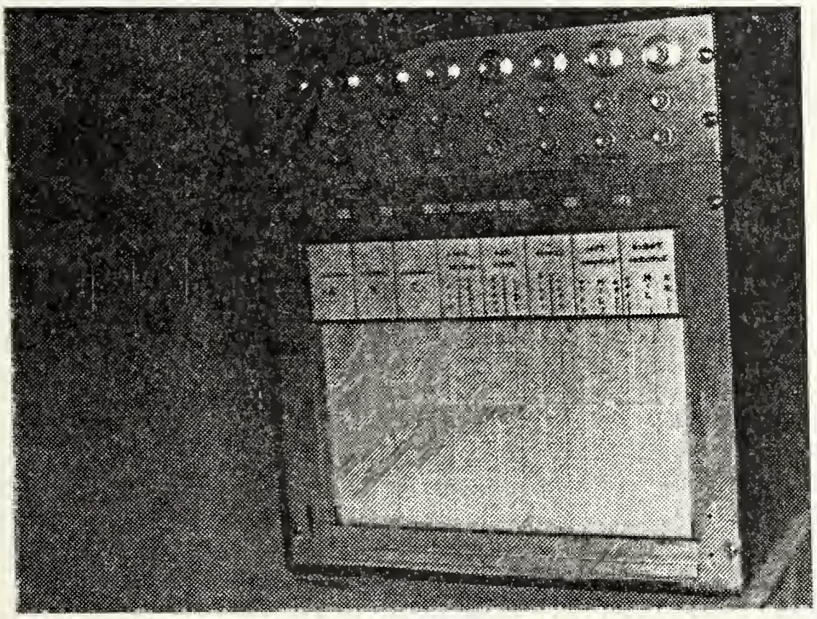


FIGURE 34
EIGHT-TRACK
ANALOG STRIP
CHART RECORDING
SYSTEM

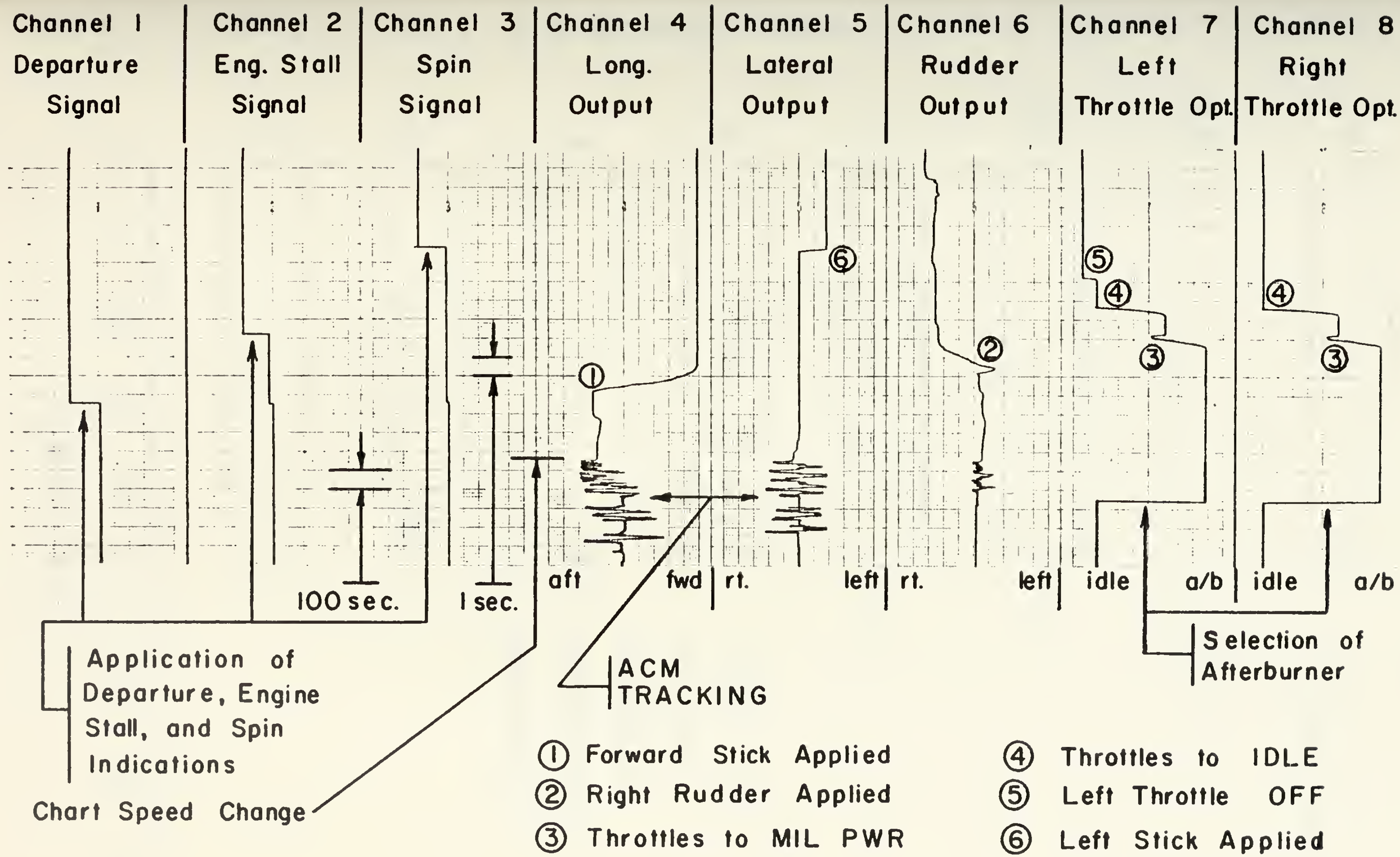


FIGURE 35. SAMPLE DATA RUN

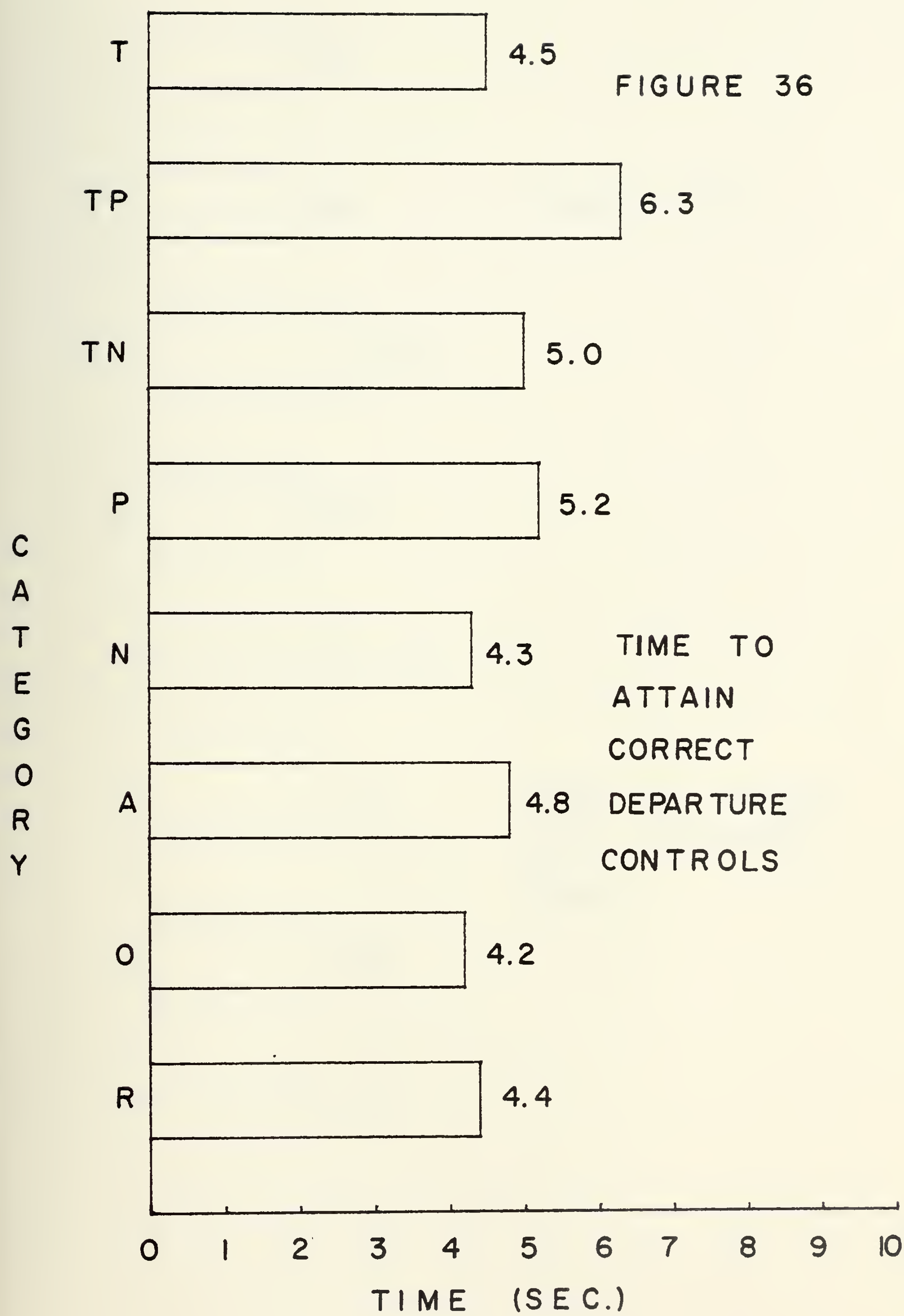


FIGURE 36
TIME TO ATTAIN CORRECT DEPARTURE CONTROLS
CATEGORY
T
TP
TN
P
N
A
O
R
4.5
6.3
5.0
5.2
4.3
4.8
4.2
4.4
0
1
2
3
4
5
6
7
8
9
10
TIME (SEC.)

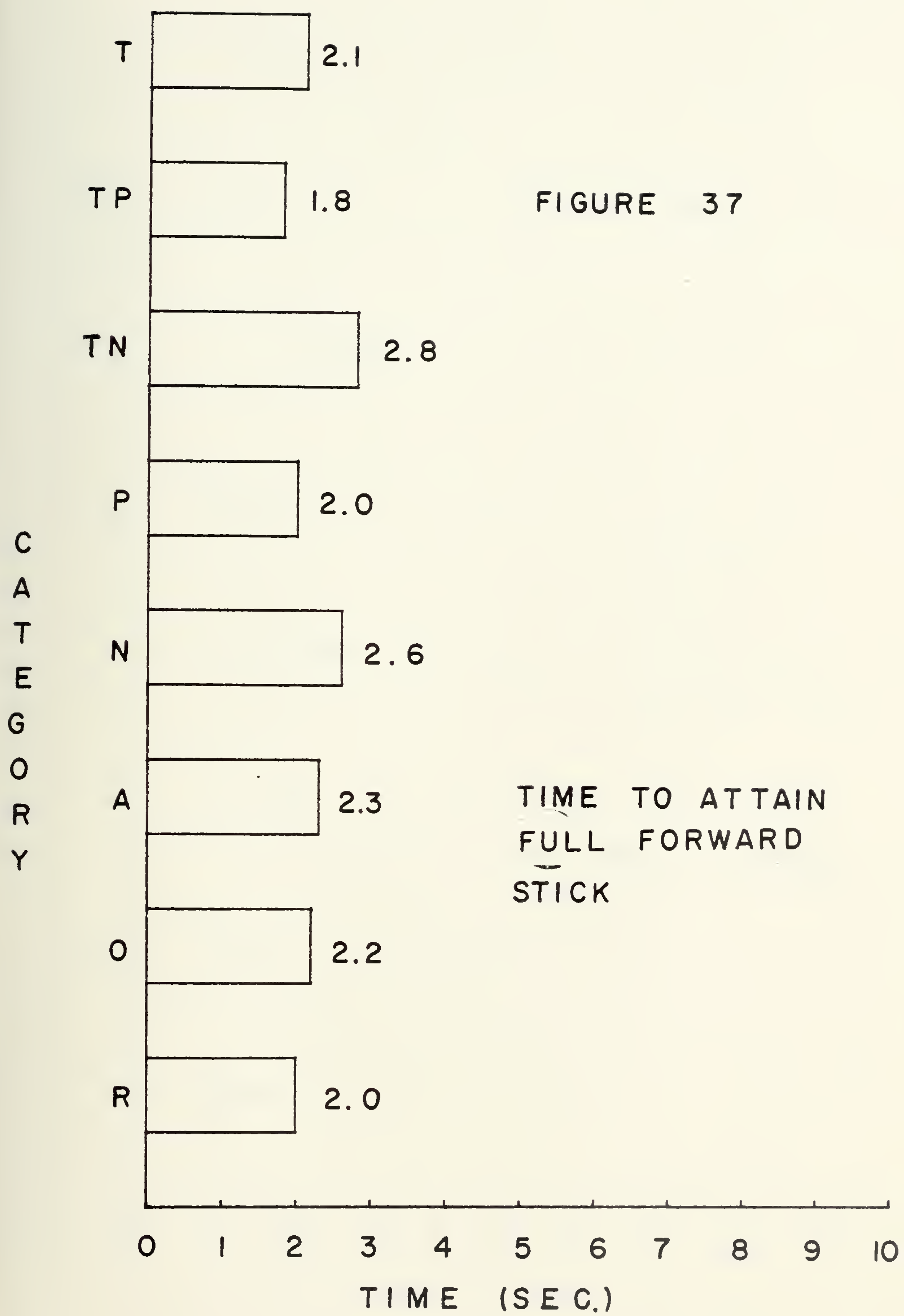
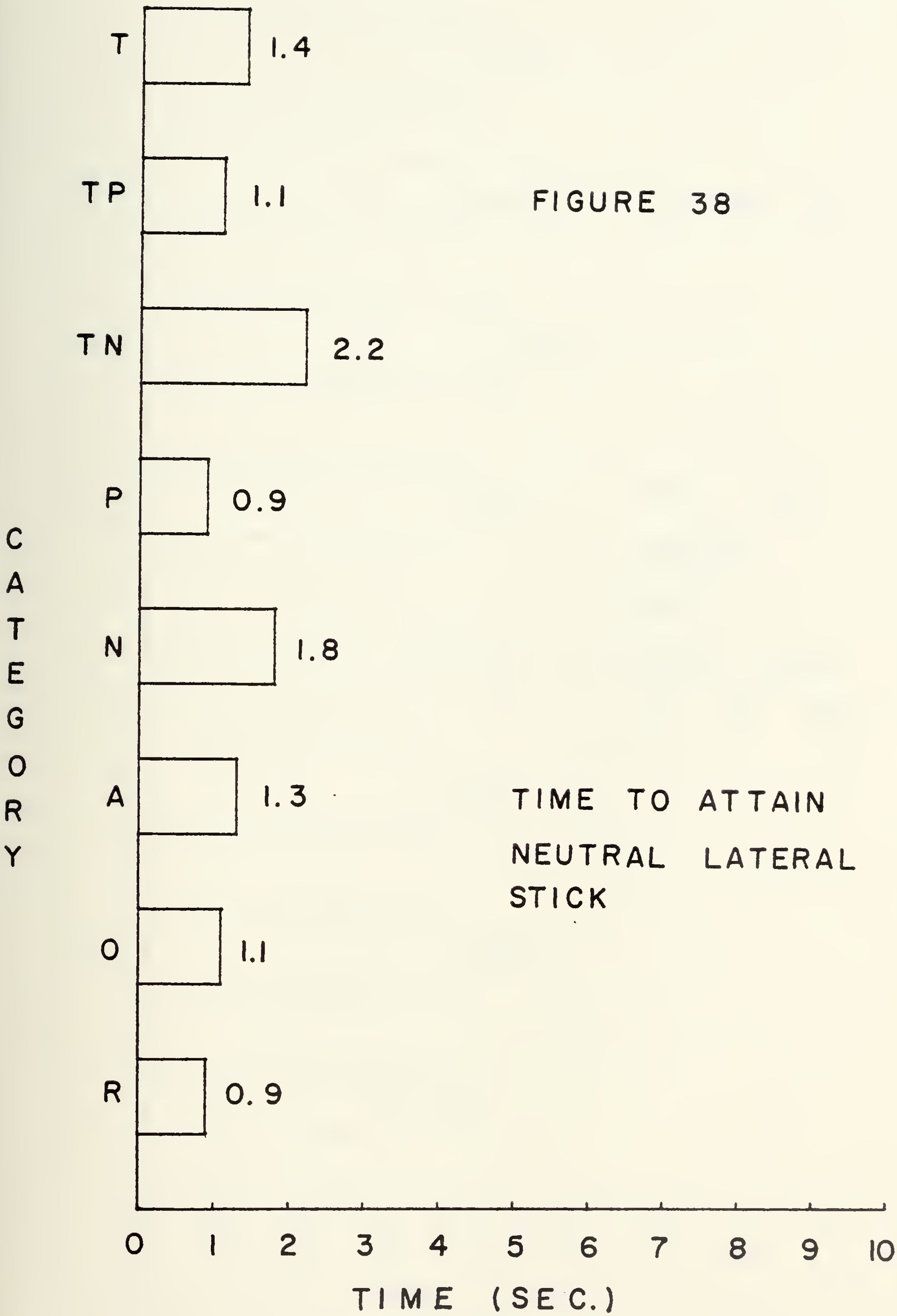

T
2.1
TP
1.8
FIGURE 37
TN
2.8
P
2.0
N
2.6
A
2.3
TIME TO ATTAIN FULL FORWARD STICK
O
2.2
R
2.0
CATEGORY
0
1
2
3
4
5
6
7
8
9
10
TIME (SEC.)

FIGURE 38



TIME TO ATTAIN NEUTRAL LATERAL STICK

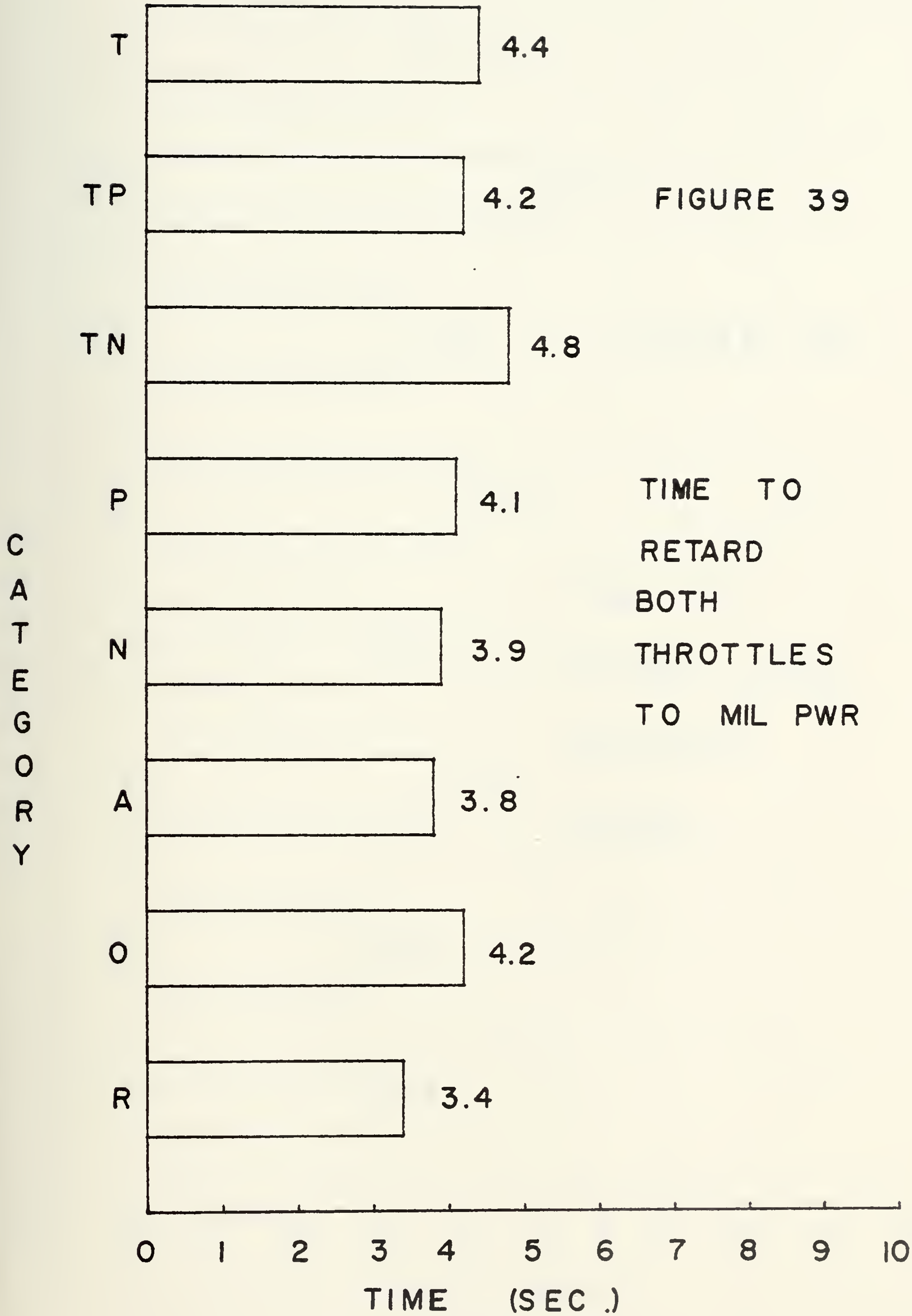


FIGURE 39

TIME TO RETARD BOTH THROTTLES TO MIL PWR

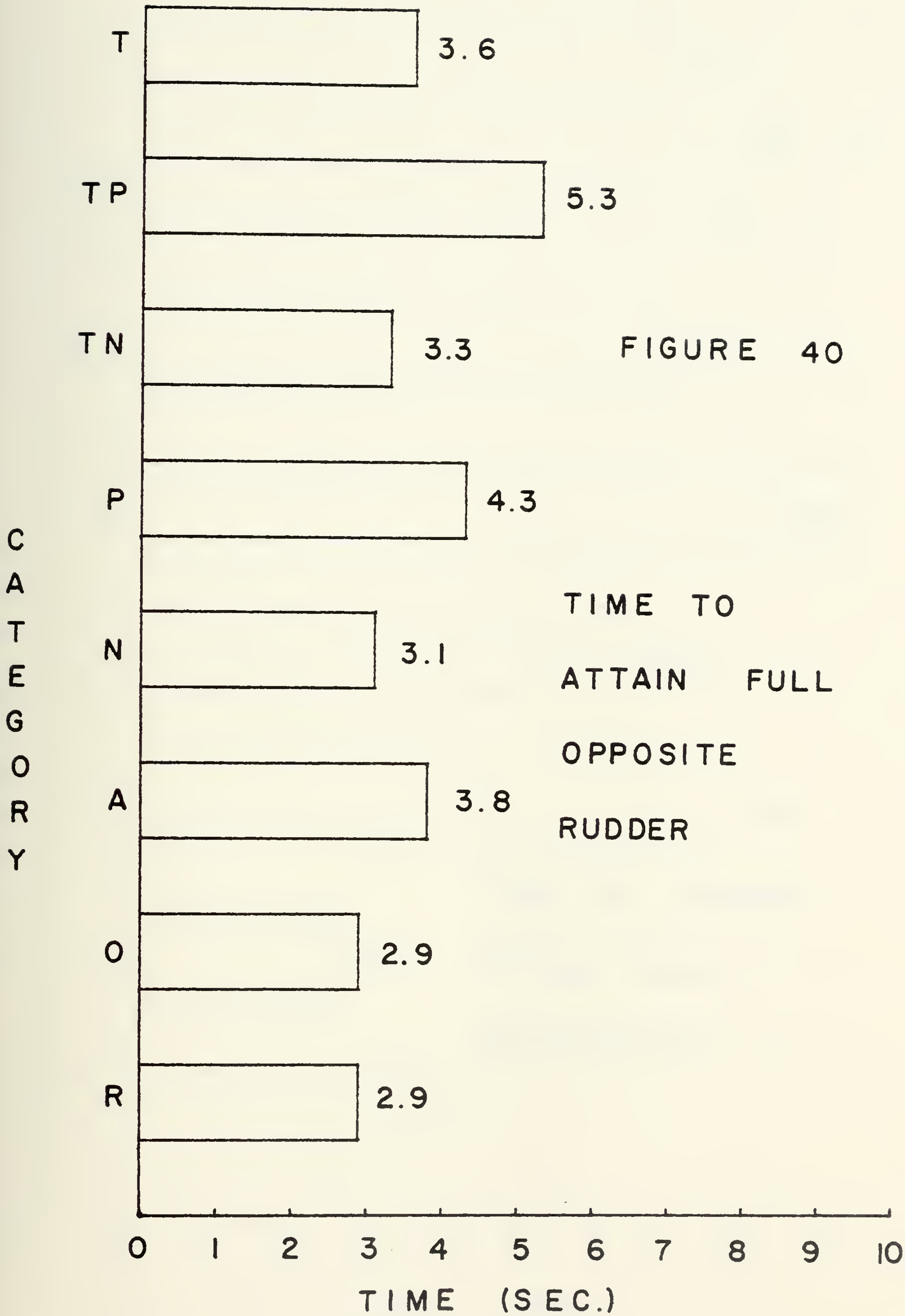


FIGURE 40
TIME TO ATTAIN FULL OPPOSITE RUDDER
CATEGORY
T
TP
TN
P
N
A
O
R
3.6
5.3
3.3
4.3
3.1
3.8
2.9
2.9
0 1 2 3 4 5 6 7 8 9 10
TIME (SEC.)

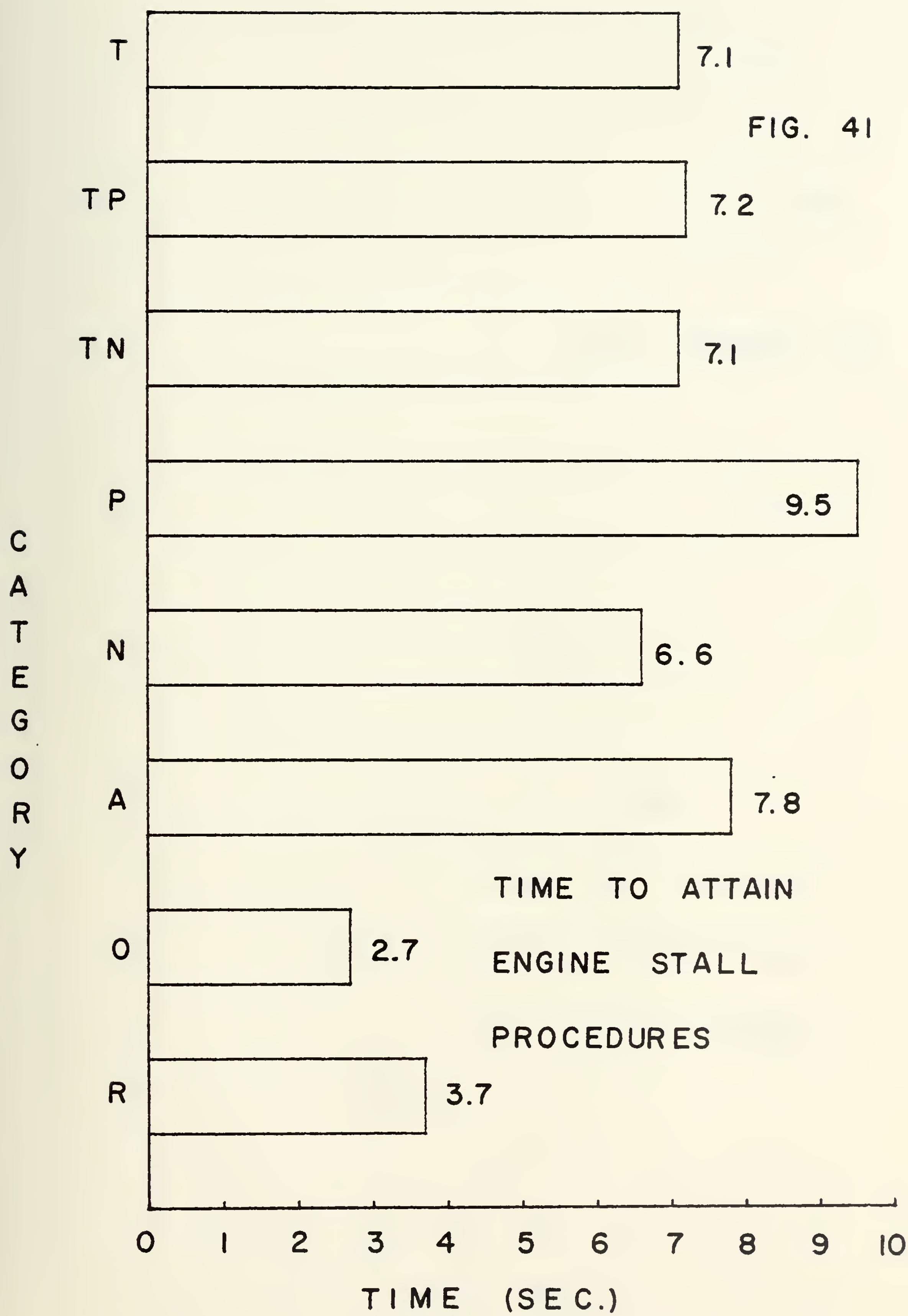


FIG. 41
T
TP
TN
P
N
A
O
R
7.1
7.2
7.1
9.5
6.6
7.8
2.7
3.7
CATEGORY
0
1
2
3
4
5
6
7
8
9
10
TIME (SEC.)
TIME TO ATTAIN
ENGINE STALL
PROCEDURES

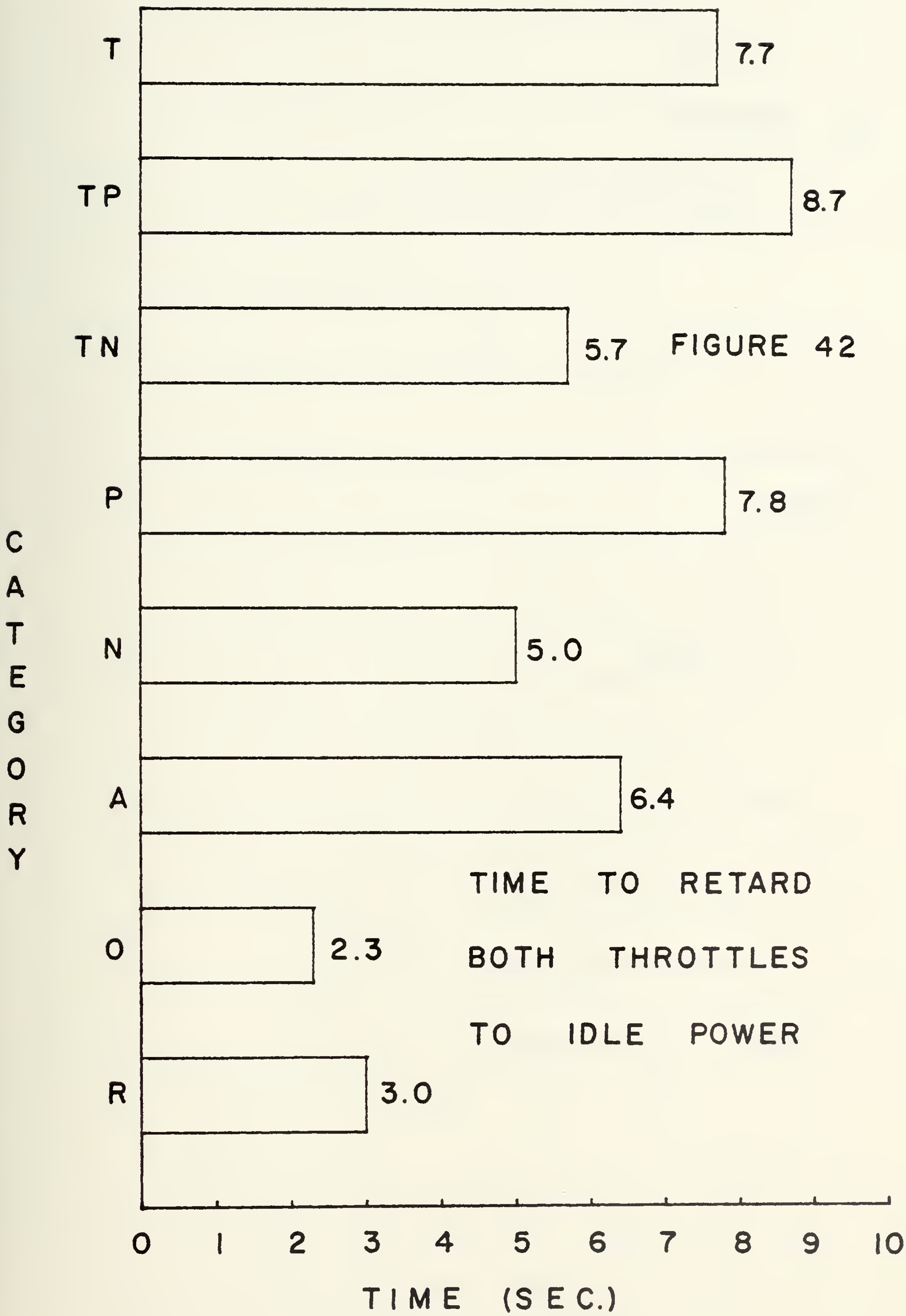


FIGURE 42
TIME TO RETARD BOTH THROTTLES TO IDLE POWER
CATEGORY
T
TP
TN
P
N
A
O
R
7.7
8.7
5.7
7.8
5.0
6.4
2.3
3.0
0
1
2
3
4
5
6
7
8
9
10
TIME (SEC.)

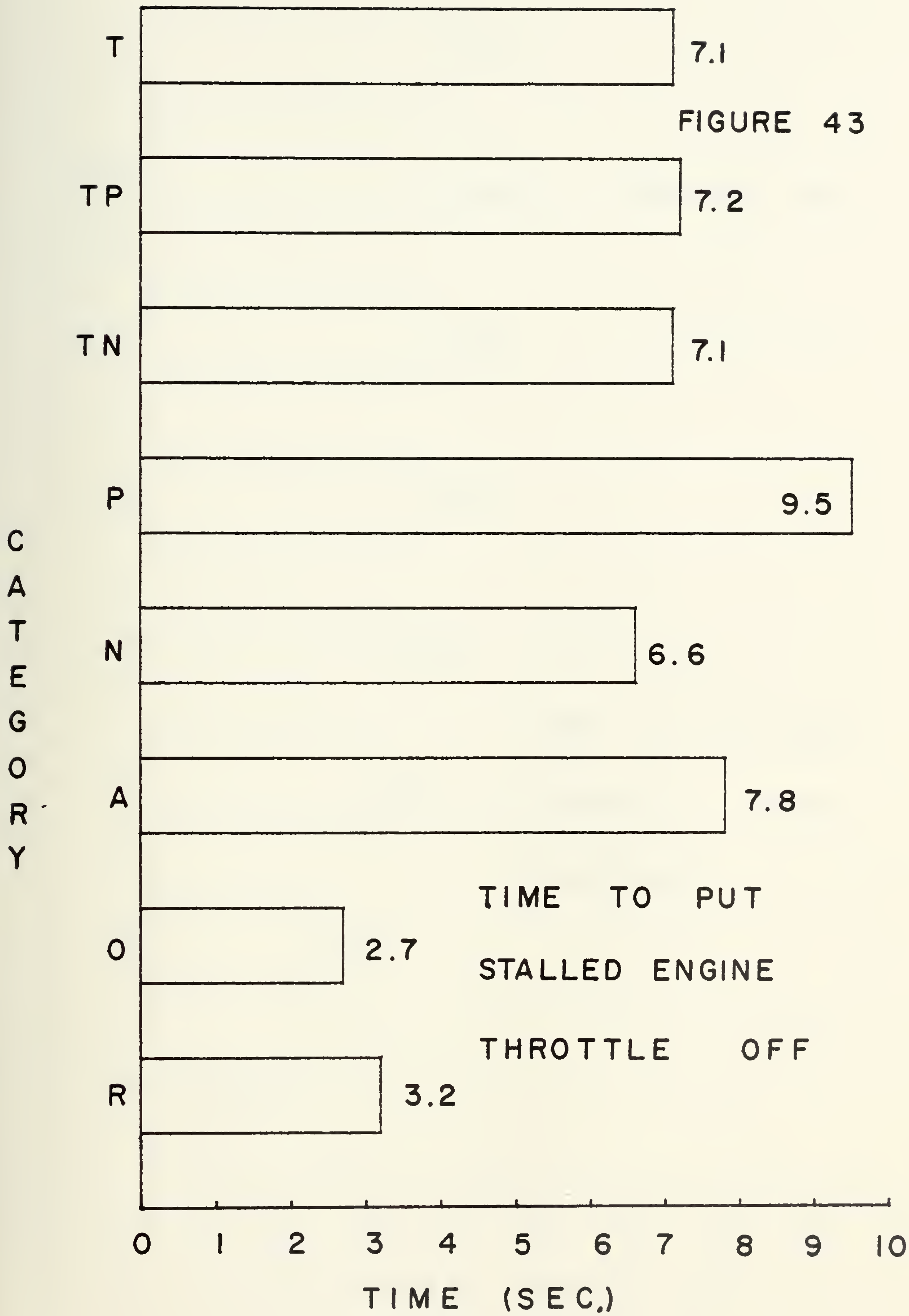


FIGURE 43
TIME TO PUT
STALLED ENGINE
THROTTLE OFF
T
TP
TN
P
N
A
O
R
7.1
7.2
7.1
9.5
6.6
7.8
2.7
3.2
CATEGORY
0 1 2 3 4 5 6 7 8 9 10
TIME (SEC.)

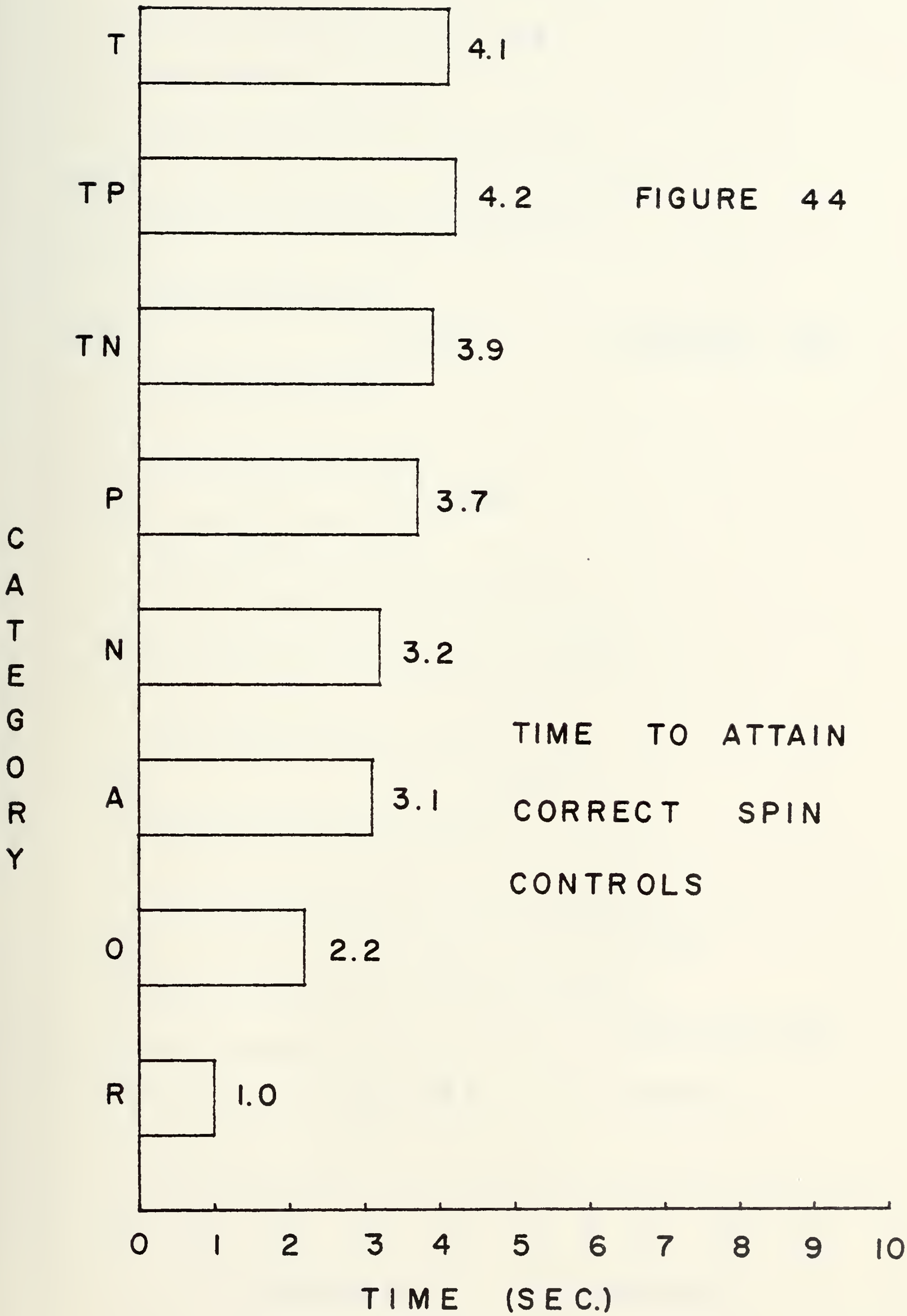
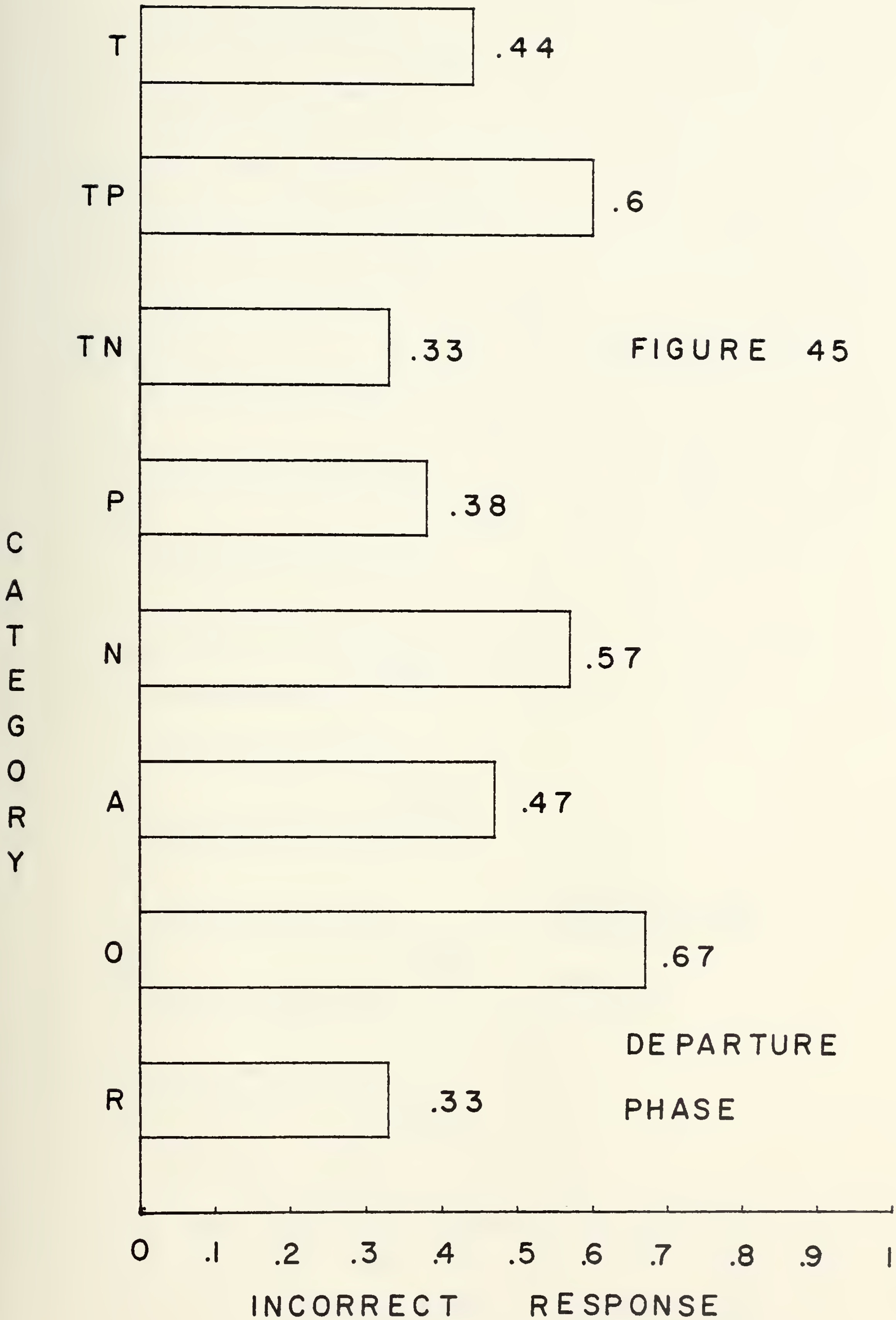


FIGURE 44
TIME TO ATTAIN CORRECT SPIN CONTROLS
CATEGORY
T
TP
TN
P
N
A
O
R
4.1
4.2
3.9
3.7
3.2
3.1
2.2
1.0
0 1 2 3 4 5 6 7 8 9 10
TIME (SEC.)


T
TP
TN
P
N
A
O
R
.44
.6
.33
.38
.57
.47
.67
.33
FIGURE 45
DEPARTURE
PHASE
CATEGORY
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
INCORRECT RESPONSE

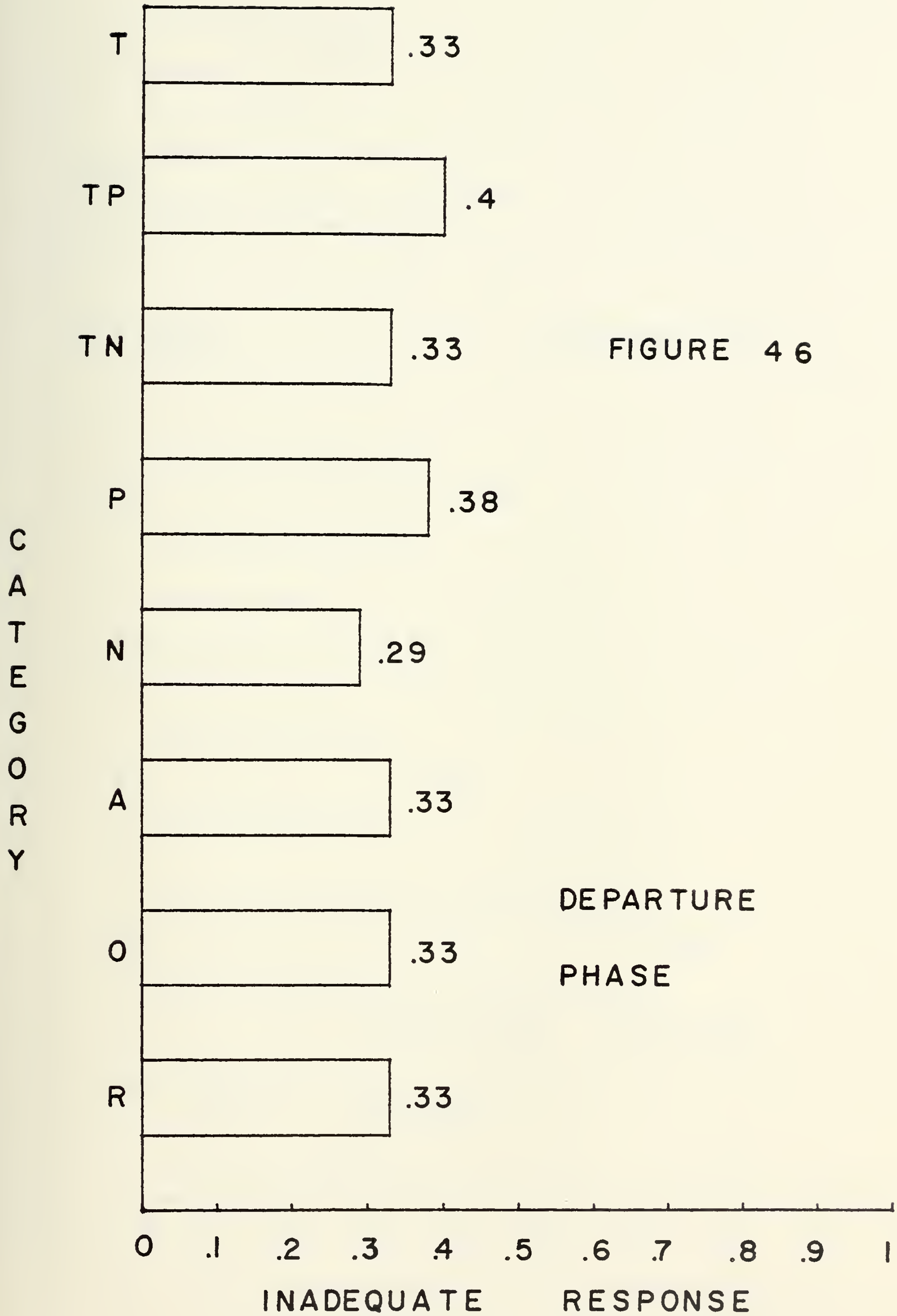


FIGURE 46

DEPARTURE PHASE

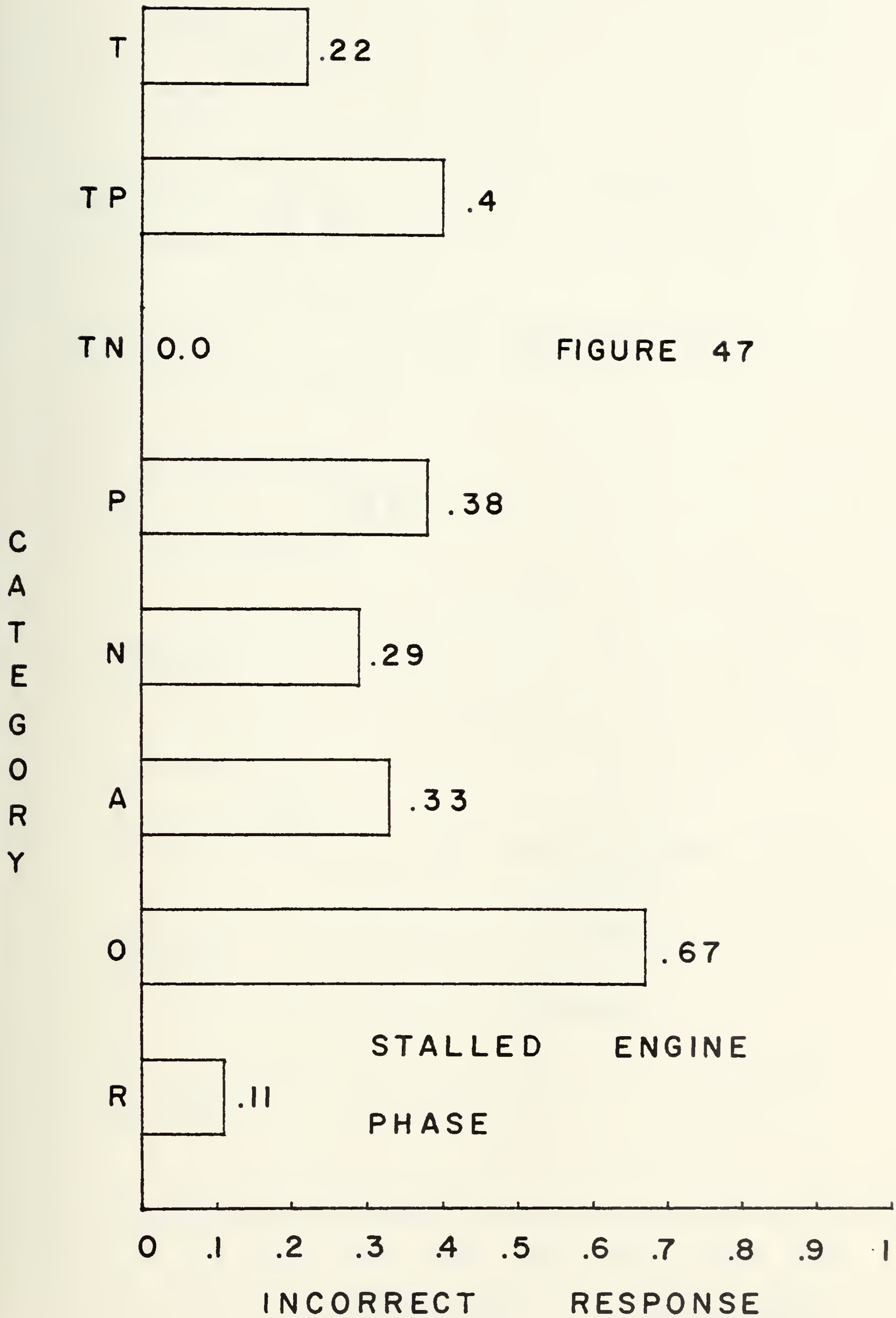


FIGURE 47

STALLED ENGINE PHASE

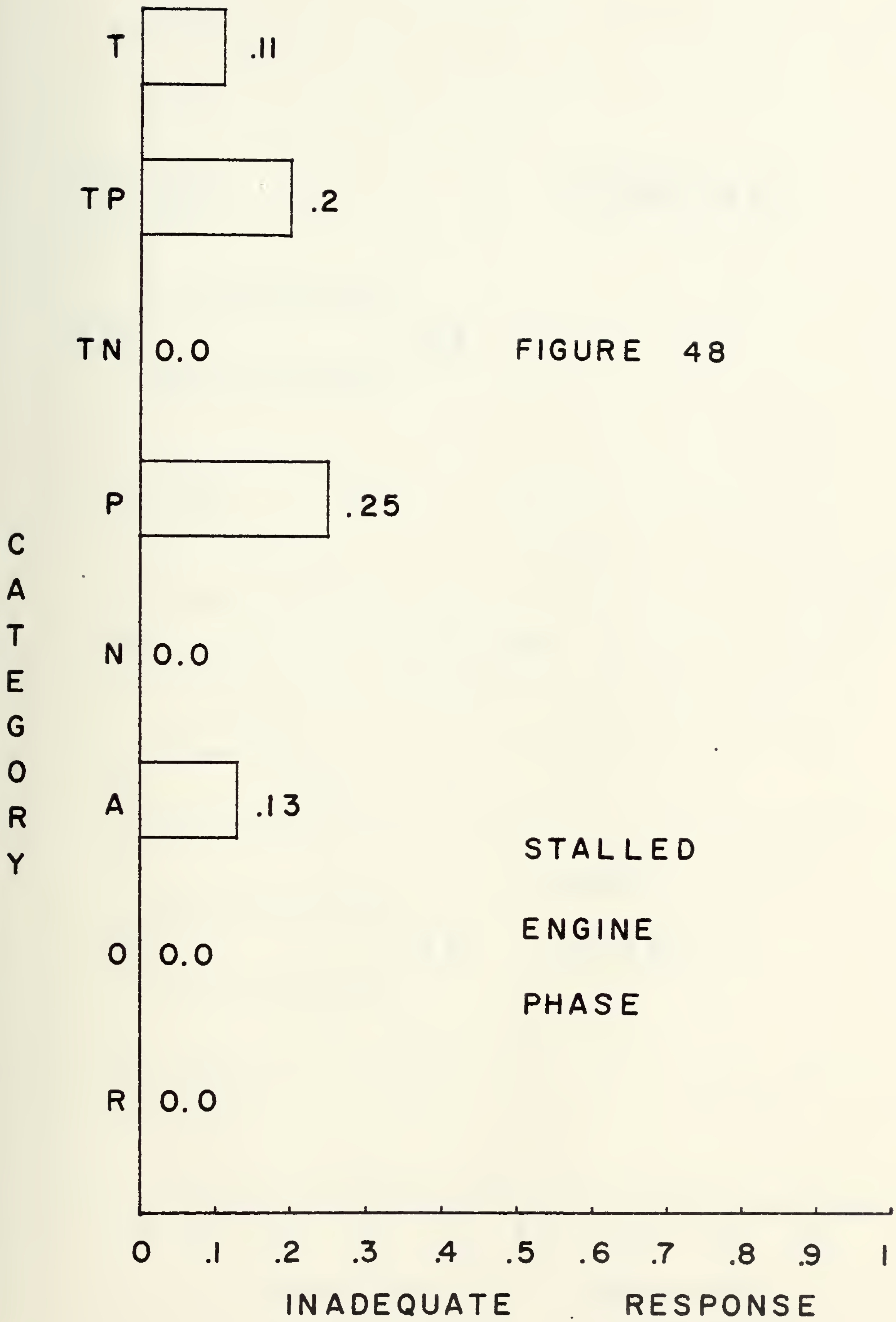
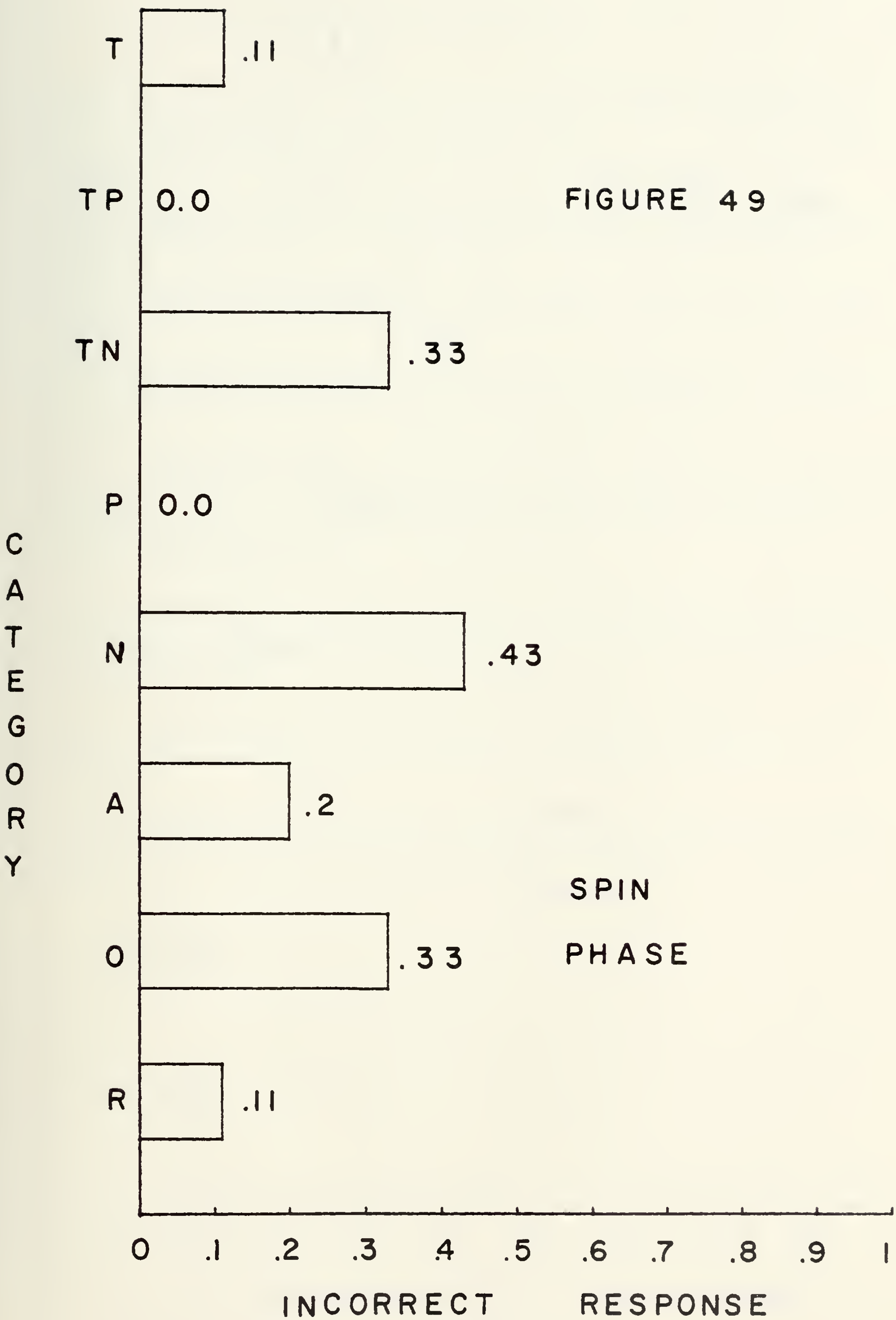


FIGURE 48

STALLED ENGINE PHASE


T
.11
TP
0.0
FIGURE 49
TN
.33
P
0.0
CATEGORY
N
.43
A
.2
SPIN
PHASE
O
.33
R
.11
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
INCORRECT RESPONSE

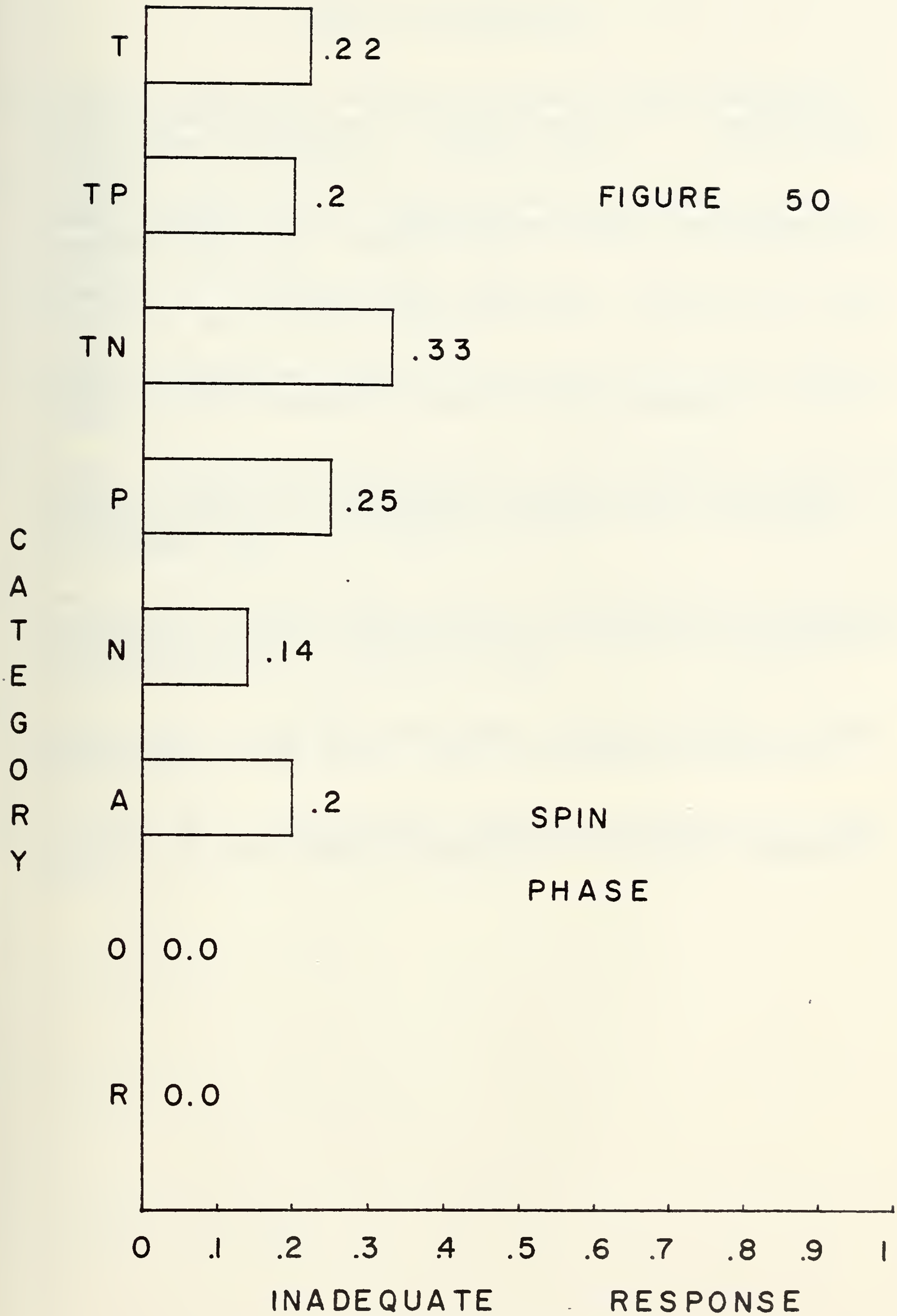


FIGURE 50
SPIN
PHASE
CATEGORY
T
TP
TN
P
N
A
O
R
.22
.2
.33
.25
.14
.2
0.0
0.0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1
INADEQUATE RESPONSE

LIST OF REFERENCES

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